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PRELIMINARY INVESTIGATION OF HYDROGEOLOGIC CONDITIONS, AND SOIL AND GROUND-WATER CONTAMINATION, AT THE VIRGINIA WOOD PRESERVING CORPORATION SITE, RICHMOND, VIRGINIA

Report To

RENTOKIL, INC.

Norcross, Georgia

BENNETT & WILLIAMS, INC.

CONSULTING GEOLOGISTS

100272

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First draft - February 28, 1986
Second Draft - September 9, 1986

Rentokil, Inc.
SupaTimber Division
Post Office Box 2248
Norcross, Georgia 30091

Attention: I. N. Stalker

Reference: Report on Investigation of the Hydrogeology, and Contamination, at the Virginia Wood Preserving Corporation Site, Richmond, Virginia.

Dear Mr. Stalker:

We are pleased to submit herewith our report on the referenced investigation. Comments from EPA Region III on the first draft of the report are addressed in Appendix 5.

As detailed in this report, our work identified several sources of contamination at the site, including the dissolution of non-aqueous phase liquids derived from process formulations, surface run-off of contaminated waters, and infiltration from the covered holding lagoon. Potential flow paths for migration of the contaminants in the subsurface have been identified.

Recommendations are made for further investigation of hydrogeologic conditions at the site, through pumping tests and additional borings, and emplacement of a water quality monitoring program. Alternative remedial methods for clean-up of the site are suggested in the report.

We will be happy to meet with you, at your convenience, to discuss our findings and recommendations in greater detail. In the meantime, if you have any further questions, please feel free to call us. Thank you very much for this opportunity to be of service.

Very truly yours,
BENNETT & WILLIAMS, INC.

Truman W. Bennett

Truman W. Bennett
Principal Geologist

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DISCLAIMER

Conclusions reached in this report are objectively based upon the data available to us at the time of forming our opinions. The accuracy of the report depends upon the accuracy of this data. Every effort is made to evaluate the information by methods generally recognized to constitute the 'State of the Art" at the time of rendering the report, and the conclusions reached therein represent our opinions. If actual conditions prove to be materially at variance with the data upon which we relied as shown in the report, a corresponding variance in actual experience as contrasted with our opinion can be expected.

Since subsurface hydrogeologic and geochemical conditions are subject to variations of both time and space, we accept no responsibility whatsoever for any actions taken as a consequence of this report that do not include our specific involvement and acquiescence.

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EXECUTIVE SUMMARY

A comprehensive subsurface investigation of the Virginia Wood Preserving Corporation site, involving 20 monitoring wells, 23 drilled borings, and 8 shallow augered holes, has been used to characterize the ground-water system, and soil and ground-water contamination.

Approximately 10 to 30 feet of clayey sand and sandy clay sediments overlie fractured granite bedrock at the site. Two stratigraphic units have been distinguished; a lower, weathered granite, and a shallow fluvial formation. These units are separated throughout much of the site by a relatively impermeable hardpan, or friable sandy clay layer, that restricts vertical ground-water flow. This restricting layer is consistent except near streams and areas of standing water, where its thickness and permeability vary.

Infiltrating surface waters tend to flow along the surface of the low permeability hardpan, or friable clayey sand layer, forming a shallow perched aquifer. Ground water within the weathered granite is confined over much of the area by the hardpan, or friable clayey sand layer, thereby creating a separate confined, or semi-confined aquifer. Ground-water flow in the vicinity of the site is generally toward North Run Creek, although flow is diverted southward, across Parham Road, in the area of standing surface water southeast of the site (Plates 4 and 5). Ground-water gradients across the Virginia Wood Preserving Corporation site averages 0.01 ft/ft in the weathered granite aquifer. In the shallow perched water table, ground-water gradients are highly variable, and sensitive to precipitation intensity. Based on a ground-water flow model of the area, discharge of ground water through the site on January 30, 1986 was estimated to be 135 gallons per day.

Soil and ground-water over much of the site, and in some areas off-site, has been contaminated through seepage of process liquids (Figures 8 and 10). At present, sources of contamination include the covered holding lagoon (Plate 2), and non-aqueous phase liquids derived from process formulations that have accumulated in the shallow perched water table (Figure 7). The non-aqueous phase liquids provide a continued source of aqueous contaminants to the ground-water system, through dissolution. Surface run-off has infiltrated into drainage areas, thereby contaminating soils.

Total estimated volume of contaminated soils is about 500,000 cubic feet (Plate 7). The area of contaminated ground water has extended beyond the site boundaries (Figure 10). Non-aqueous phase liquids appear to be immobile at this time, and confined to an area of approximately 134,000 square feet on the site. With existing data, total volumes of light immiscible liquids can only be approximated, with the probable range estimated to be between 4,000 and 20,000 gallons.

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Remedial methods for clean-up of the site are recommended (Plate 8). Essential elements include excavation and disposal of contaminated soils, and hydraulic isolation of the surface and subsurface. Natural and enhanced degradation of contaminants should be evaluated, particularly for off-site treatment, where it may be more efficient than hydraulic recovery. Monitoring of water quality, in existing and additional monitoring wells should be continued.

PRELIMINARY INVESTIGATION OF HYDROGEOLOGICAL CONDITIONS, AND SOIL AND GROUND-WATER CONTAMINATION, AT THE VIRGINIA WOOD PRESERVING CORPORATION SITE, RICHMOND, VIRGINIA

INTRODUCTION

The Virginia Wood Preserving Corporation site, a division of Rentokil, Inc., is in Richmond, Virginia, 1000 feet north of Parham Road, and 2.4 miles west of Interstate 95. The property consists of approximately 10 acres used to treat and temporarily store lumber. The location of the site is shown in Figure 1. A topographic contour map of the study area is shown in Plate 1.

Previous investigations at the Virginia Wood Preserving Corporation site revealed contamination of soil and ground water by creosote, pentachlorophenol, and CCA wood preserving formulations. It appears that this contamination occurred by seepage of process liquids and waste.

At the request of Rentokil, Inc., a detailed subsurface investigation of the Virginia Wood Preserving Corporation site has been conducted. Field work began in August, 1985, and was completed in January, 1986. The goal of this program was to obtain sufficient basic data to characterize the ground-water system and contaminant distribution. These data are used to develop systematic and comprehensive approach to clean-up operations.

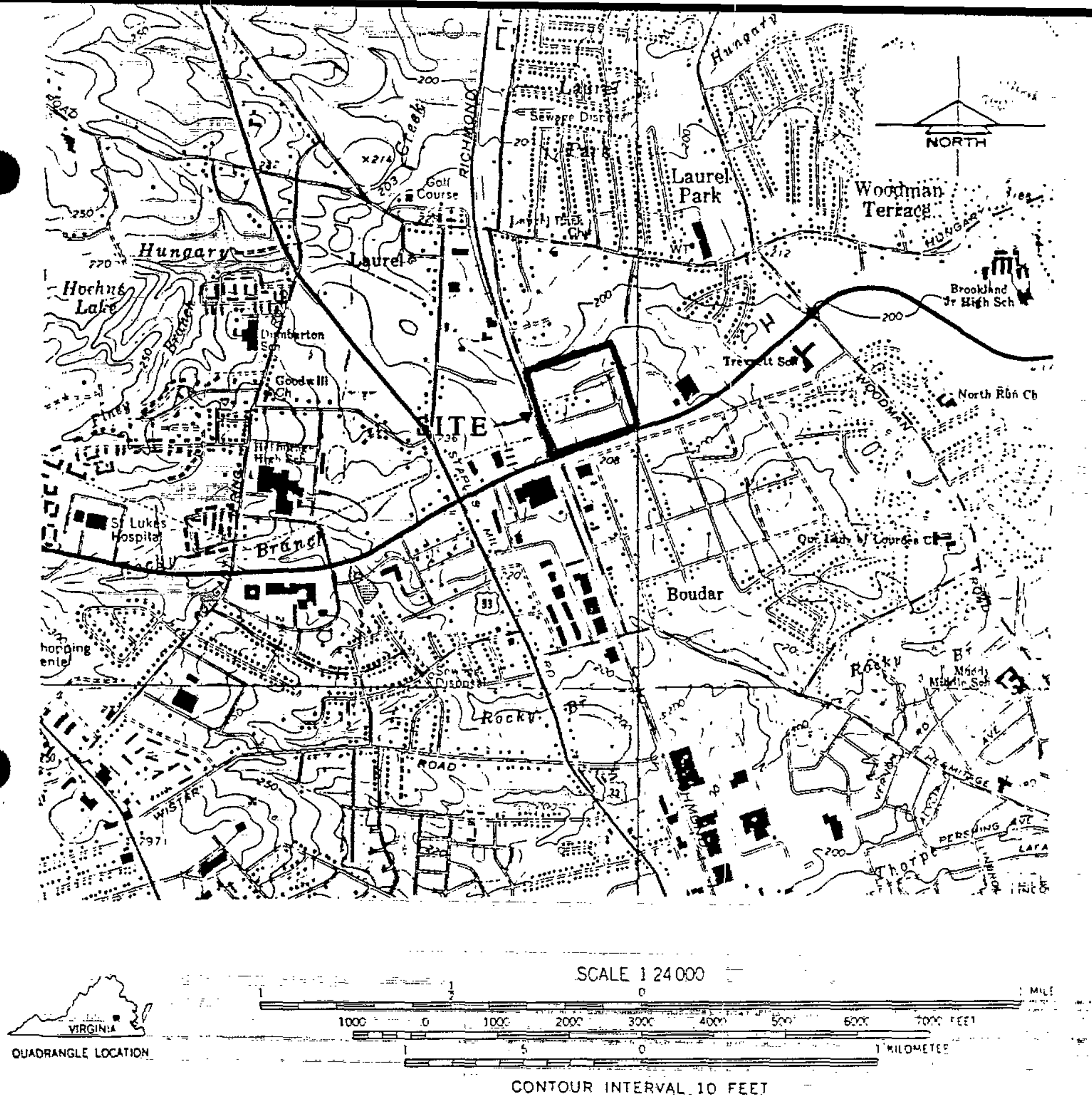

Fig. 1 - Location of Virginia Wood Preservers site.

SCOPE OF WORK

During this investigation, consideration has been given to the available geological and hydrogeological information relating to the site. This body of information includes: reports summarizing previous investigations by Environmental Laboratories, Inc. and Dvorak Geotechnical Services, Inc.; published data gathered by the Virginia Division of Mineral Resources; published soils maps and descriptions of the area from the USDA Soil Conservation Service; and aerial photographs and stereo pairs from the Virginia Department of Transportation.

Five monitoring wells and nine borings were drilled at the site during previous investigations. The five monitoring wells are wells 1, 2, 3, 4 and 5, and the nine borings are B2, B13, B18, B21, P, Q, R, V, and Y. These wells and borings are shown on the site location map (Plate 2). The descriptions of soil materials are reprinted from previous reports by Dvorak Geotechnical Services, Inc., in Appendix 1. The well construction details for the monitoring wells installed previously have been reviewed to determine possible cross-connections, and to evaluate possible interactions between the construction materials used and the contaminants present.

Available well construction details and results of water quality analyses for each of the existing deep water supply wells on-site, designated as D1 and D2 on Plate 2, have been reviewed regarding the potential for cross-connection and surface leakage along the well casing. Recommendations are made for preventing any further cross-contamination and evaluating any potential impact for contamination of the deep confined granite aquifer.

Drainage in and around the site has been studied, and a surface run-off management plan which will prevent potentially contaminated surface water from leaving the site has been recommended. Characteristics of the run-off management plan, which can be tied into various remedial action plans, have been noted.

Locations for 14 additional monitoring wells and 14 additional borings installed during this investigation are shown on Plate 2. Five of the monitoring wells were screened above the weathered granite, adjacent to monitoring wells screened above unweathered bedrock, to determine the hydraulic relationships between the weathered granite and the overlying regressive fluvial sediments. Eleven of the shallow borings were screened to gain additional information on ground-water flow within the shallow perched water aquifer. Construction information on the monitoring wells is summarized in Table 1. A boring log, including the geologists description and construction details, of all borings and monitoring wells, is presented in Appendix 1.

The monitoring wells and borings installed during this investigation were drilled by the hollow-stem auger method, with split-spoon and Shelby tube samples taken as directed by the Project Geologist. All materials were steam-cleaned prior to each use, and samples of condensed steam on steam-

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TABLE 1 - "As-builts" for monitoring wells installed during this investigation

Boring	Surface Elevation	Casing Elevation	Top Bentonite Slurry	Bottom Bentonite Slurry	Top Sand Pack	Bottom Sand Pack	Bottom of Well
GMW2A	208.0	209.0			205.0	201.0	201.0
GMW3A	209.1	209.6	209.1	208.9	205.9	202.5	202.5
GMW8	207.1	208.2	207.1	204.2	203.3	199.5	199.5
GMW9	207.5	208.4	207.5	200.7	199.9	193.3	193.3
GMW9A	207.5	208.6			204.5	200.5	200.5
GMW10	210.1	210.4	210.4	199.2	197.2	190.2	190.2
GMW10A	210.4	211.8			207.4	203.4	203.4
GMW11	202.0	205.3			196.3	192.8	192.8
GMW11A	202.0	205.0			201.0	197.0	197.0
GMW12	209.4	210.0	209.4	198.4	197.0	191.4	191.4
GMW13	207.8	208.8	206.8	198.3	194.8	188.8	188.8
GMW14	213.0	213.7	213.0	200.7	198.8	190.9	190.9

TABLE 1 (contd.)

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Boring	Type Riser/Screen	Top Upper Bentonite Pellets	Bottom Upper Bentonite Pellets	Top Lower Bentonite Pellets
GMW2A	2" stainless steel	208.0	205.0	
GMW3A	2" stainless steel	206.9	205.9	
GMW8	2" stainless steel	204.0	203.3	199.4
GMW9	2" stainless steel	200.7	199.9	
GMW9A	2" stainless steel	207.5	204.5	
GMW10	2" stainless steel	199.2	198.2	190.2
GMW10A	2" stainless steel	209.9	207.8	
GMW11	2" stainless steel	202.0	196.3	191.3
GMW11A	2" stainless steel	209.4	208.9	
GMW12	2" stainless steel	198.3	194.8	188.8
GMW13	2" stainless steel	190.9	189.7	
GMW14	2" stainless steel	200.7	198.8	190.9

Boring	Bottom Lower Bentonite Pellets	Screen Slot	Top Screen	Bottom Screen
GMW2A		20 slot	205.0	201.0
GMW3A		20 slot	204.8	202.5
GMW8	198.5	20 slot	203.3	199.5
GMW9		20 slot	199.9	193.3
GMW9A		20 slot	204.5	200.5
GMW10	188.0	20 slot	197.2	190.2
GMW10A		20 slot	205.4	203.4
GMW11	189.7	20 slot	196.3	192.8
GMW11A		20 slot	199.0	197.0
GMW12	187.8	20 slot	197.0	191.4
GMW13		20 slot	194.8	188.8
GMW14	189.7	20 slot	198.8	190.9

cleaned augers and well casings were collected at regular intervals for quality control. When all drilling, sampling, casing and screen installation procedures were complete, all wells were developed by pumping or bailing.

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Undisturbed, Shelby tube samples of representative subsurface materials were taken during the drilling operations. Samples were submitted for laboratory analyses of permeability, grain size distribution, and specific gravity of the sediments. These analyses were conducted by the soils laboratory of Dunbar Geotechnical Engineers of Columbus, Ohio. Twenty-one additional split spoon samples were tested for Atterburg Limits (ASTM D423, D424), and grain size distribution (ASTM D422) by Dvorak Geotechnical Services, Inc., of Richmond, Virginia. Results of the soils laboratory analyses are shown in Table 3 and Appendix 2.

Surface soil samples were collected at 13 sites, from depths of two inches to two feet, to supplement soil samples collected from the borings and monitoring wells. Sixty-six soil samples were selected by the Project Geologist for analysis of total recoverable phenols.

Upon completion of drilling and developing the monitoring wells, each of the wells was evacuated a minimum of five times, until pH and specific conductance stabilized, and then water samples were collected. The sampling was performed by Environmental Laboratories, Inc. Water sampling was performed utilizing a teflon bailer or peristaltic pump. All samples were collected in accordance with standard field procedures, preserved, refrigerated, and

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transported to the laboratory within eight hours after collection. A list of chemical parameters analyzed is shown in Table 2. Comprehensive analyses of phenolic and polynuclear aromatic hydrocarbon compounds, which would have allowed evaluation of the contaminants and natural degradation of the contaminants, were not completed because of apparent instrumental failure. In-situ measurement of pH, specific conductance, dissolved oxygen, and temperature was completed at each monitoring well. These parameters are subject to change within the time to transport the samples to the laboratory. In the case of dissolved oxygen, significant changes in the concentrations may take place even during the sampling process.

Ground water and soil contamination contour maps have been prepared. These maps, in conjunction with the groundwater flow model, have been used to estimate the potential for migration of the contaminants off-site.

In-situ permeability tests were conducted on monitoring wells 2, 3, 3A, 5, and 10. These tests were completed using a low discharge peristaltic pump. Drawdowns and recoveries were measured for each well, and permeability of the screened zone was determined from graphical analysis of time of pumping versus normalized head differential. Results are shown in Table 4.

An earth resistivity survey was attempted in and around the study area. Because of interference by electrical lines, railways, roads, sewers, and the presence of standing water in areas around the site, it was not possible to

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Table 2 - Chemical parameters measured in soil and ground-water samples during this investigation.

Parameters
Total alkalinity
Total Kjeldahl nitrogen
Nitrate
Sulfate
Total dissolved solids (TDS)
Chloride
Methylene blue active substances (MBAS)
Magnesium
Iron
Sodium
Potassium
Carbonate alkalinity
Nitrite
Copper
Chromium
Arsenic
Total phenols
Chemical oxygen demand
Total organic carbon
Pentachlorophenol
Creosote
Temperature
pH
Conductivity
Dissolved oxygen

locate a sufficient number of resistivity stations to provide meaningful data on the stratigraphy or extent of contamination.

Geologic cross-sections from previous investigations, as well as soil data from borings and monitoring wells installed during this investigation, are used to develop the stratigraphic framework of the site. A fracture trace analysis of bedrock of the site was used to identify any fractures in the underlying bedrock.

The geologic and hydrogeologic data collected during this investigation were used to develop a three-dimensional ground-water flow model. The model is used to evaluate potential vertical and horizontal flow paths in the subsurface materials, and determine the possible lateral extent of the contaminant plume. It will also provide the basis for evaluating which of the suggested remedial measures will allow the most timely and cost efficient recovery of contaminated ground water. In specific, the model is used to: (1) investigate the hydraulic relationship between the weathered granite and the overlying regressive fluvial sediments, and the effect of the hardpan, or semi-confining layer, on ground-water flow and contaminant migration from the shallow perched water table to the underlying semi-confined aquifer; (2) determine the hydraulic relationship between both the shallow perched water table and the underlying semi-confined layer, with the stream north of the site and the ponded areas east and southeast of the site; and (3) provide a method for comparing the expediency and efficiency of alternate remedial action plans, to determine the most beneficial and cost-efficient management plan for the site.

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Added by I. N. Stalker, Rentokil, Inc. on 26th September 1986

SITE HISTORY (Page 14)

Please note that additional historical information about the site has been uncovered since this report was redrafted.

The most significant change concerns the "Blow-down Sump" referred to on Page 14, paragraph 1. An early drawing shows that the sump was in fact one section of concrete sewer conduit, buried with its axis vertical, and its upper end level with the grade. This sump was installed adjacent to the first treating cylinder.

The sump was a simple oil/water separator. The lower water phase was withdrawn by a pipe let into the conduit at a low level, and carried to the early pond (on the site of the current concrete pond).

As our understanding of historical detail does change with time, we recommend that readers check with Rentokil, Inc. before making decisions based on previous events.

Ian Stalker

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Construction work on the Virginia Wood Preserving Corporation site began in June, 1956. The plant initially treated highway fence posts and building poles with CZA (a formulation consisting of oxides of chromium, zinc, and arsenic) and a water repellent containing mineral spirits and pentachlorophenol. At that time, one treatment cylinder was used, and pollution control consisted of a blow-down sump with a trap for waste water discharge. Wood-lined open trenches collected spilled liquid from the cylinder and routed the liquid into the blow-down trench. Oil was recovered periodically from the blow-down sump. The location of the blow-down sump was approximately where the concrete holding pond is at present (see Figure 2). The depth of excavation of the blow-down sump is not known. Based on the materials encountered in a boring near the concrete holding pond (boring CS, shown on Plate 2), it appears that the original excavation probably penetrated to at least 4.2 feet, and was subsequently filled to present grade. Approximately 3.1 feet of contaminated clay, probably covered after the removal of the blow-down sump, was found in boring CS.

In 1959, vapor drying of oak decking was initiated using xylene vapor, and the cooling pond, shown in Figure 2, was installed. After vapor-drying, the lumber was treated with pentachlorophenol in a solution of mineral spirits. The blow-down sump was removed, and replaced with the concrete holding pond used for separation and evaporation of waste water. The concrete holding pond was linked through an underground pipe to a holding lagoon. This lagoon is no longer used, and is referred to as the covered holding lagoon shown on Figure 2. The lagoon was unlined, and based on aerial photographs taken in 1965 and 1969, overflow of the lagoon occurred. The depth of the lagoon is not known, however it is likely that the bottom elevation is within the hardpan layer forming the bottom portion of the regressive fluvial sediments.

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In 1964, a second treatment cylinder to be used for creosote, and a creosote-water separator, were installed. A fire retardant, consisting of ammonium phosphate and sulphate salts, was used between 1965 and 1977. In 1966, the use of CZA was discontinued, and CCA (a formulation consisting of oxides of copper, chromium, and arsenic) was used. The use of xylene was also discontinued.

In 1969, a dry-kiln was installed for treatment of decking. A new system, eliminating the need for discharge into the covered holding lagoon, was installed in 1974. New oil/water separators were installed, along with a spray evaporator in the concrete holding pond to evaporate waste water. In 1977, treatment with fire retardants was discontinued. A third creosote cylinder and second dry kiln were installed in 1979.

In 1981, the use of pentachlorophenol was discontinued, and in November, 1983, the use of creosote was discontinued and the cooling pond was filled in. At present, only the

CCA formulation is used for treatment at the site.

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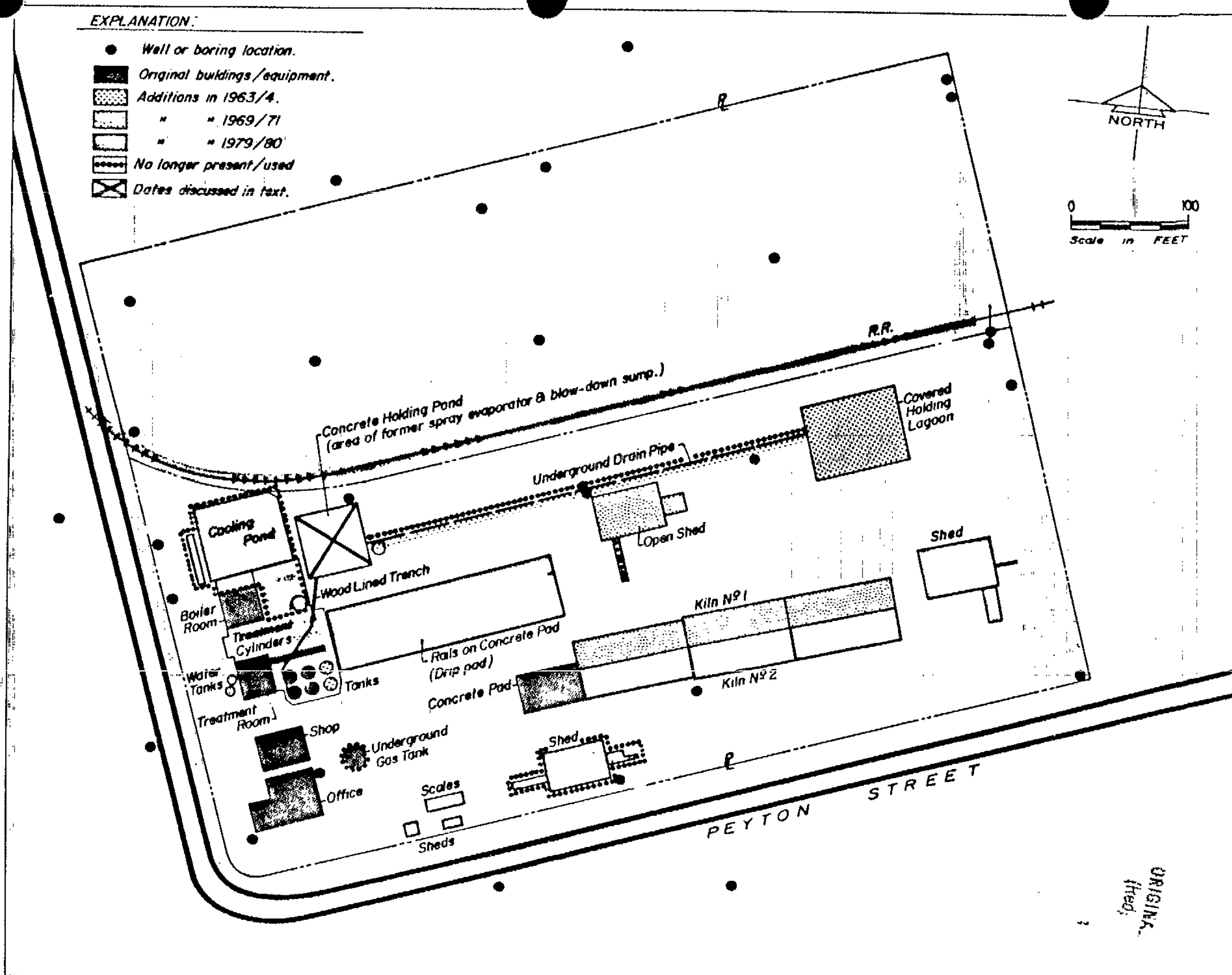

Fig. 2 - Map of Virginia Wood Preservers site showing elements of the Wood treating operation.

GEOLOGICAL DESCRIPTION OF THE SITE

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The site is within the Piedmont physiographic province, near the Fall Zone, which is a boundary separating the Piedmont from Coastal Plain sediments. Topography in the area is mature, characterized by gently rolling terrain. The site is on a nearly level upland flat, sloping gently to the north. Maximum elevation is 213.5 feet above mean sea level (amsl) in the southwestern corner of the site. Surface drainage is to the north and northeast across the property, towards North Run Creek. Minimum elevation is 207.6 feet (amsl) in the northeast corner of the site. A topographic contour map of the study area is shown in Plate 1. Stratigraphic cross-sections are shown in Appendix 4. Cross-section traverses are shown on the site location map (Plate 2).

Bedrock beneath the site is the Upper Paleozoic Petersburg Granite. Unweathered, this bedrock is a coarse-grained, porphyritic granite with abundant feldspar, muscovite, and biotite. The unit is exposed approximately 6000 feet east of the site, and a small exposure in a railroad cut occurs approximately 9000 feet north of the site. The gradient on the surface of the granite slopes gently to the east, at approximately 80 ft/mile, toward the Atlantic Ocean. Figure 3 shows bedrock elevations at the site. Depth to bedrock for this investigation is defined as auger refusal. Because of the uneven weathering of the

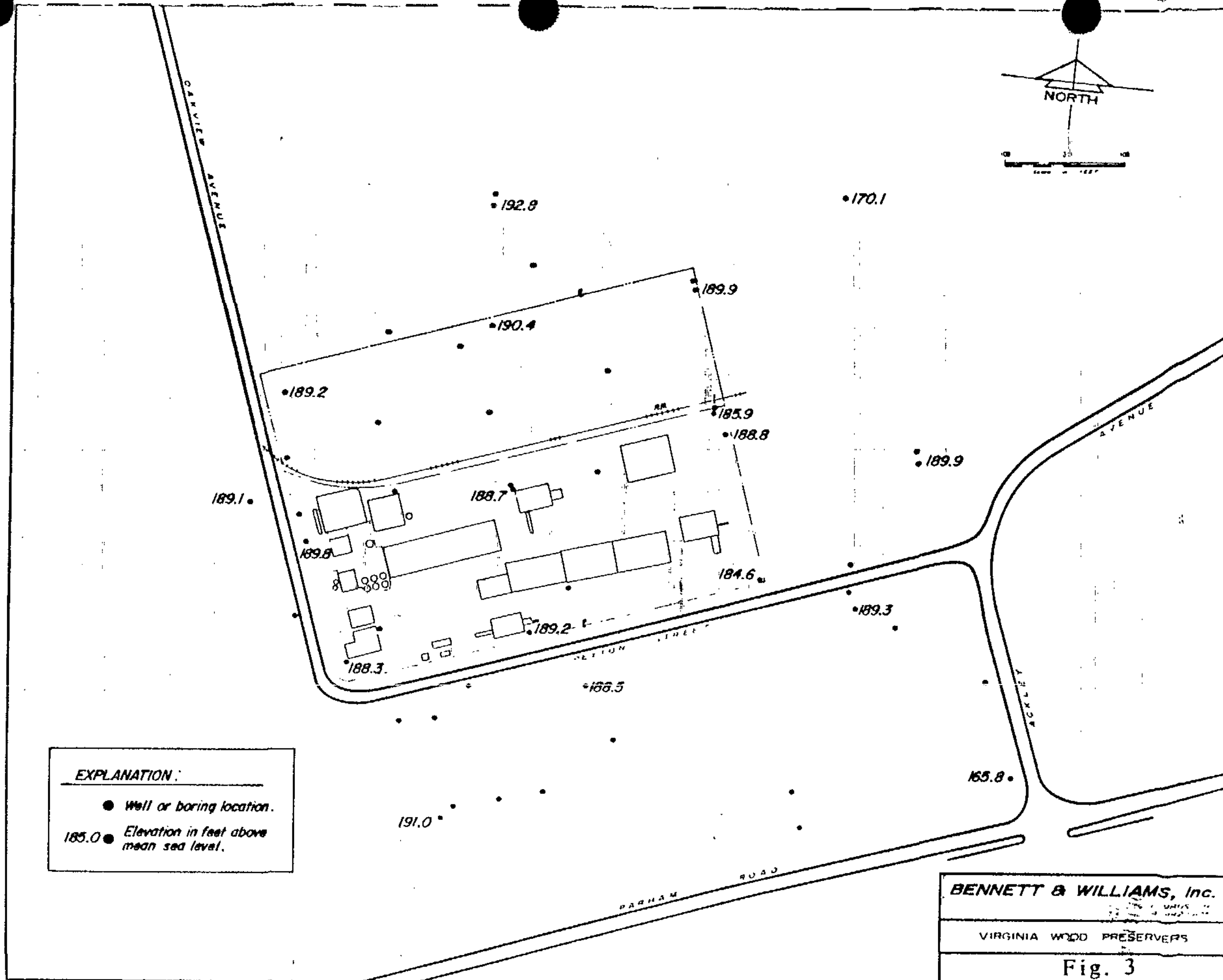

Fig. 3 - Elevations of unweathered bedrock detected by auger refusal in wells and borings.

Petersburg Granite, the regional slope of the unit is not readily apparent from Figure 3.

Joints in the Petersburg granite tend to have either a very steep dip, or are horizontal, and trend in a northerly or easterly direction. A fracture trend analysis of the site has revealed no surface expression of joints. The deep water supply wells on-site are probably drilled into fracture systems which provide a source of ground water through interconnected joints. Deep water well No. 1 (designated as D1 on Plate 2) was drilled to a depth of 425.6 feet, and deep water well No. 2 (D2) was drilled to 244.6 feet.

Weathering of the bedrock unit has produced a disintegrated granite that consists of light gray and white, poorly-sorted, fine to coarse-grained sand with 15 to 35% silt, and 15 to 40% clay. In some areas a granite residium with 60% or more fine to coarse sand has developed. Iron staining is common, imparting a red coloration to the weathered granite. Weathering has destroyed much of the original rock texture and structure.

Table 3 summarizes laboratory tests of engineering properties conducted on the soil samples. The majority of the samples of weathered granite were classified as ML and CL type soils according to the Unified Soil Classification System. One sample was classified as CH, and two other samples were classified as SC. The plasticity index varies from non-plastic to 30%, and the liquid limit varies from 20

Boring	Depth(ft)	Void Ratio	Liquid Limit(%)	Plastic Limit(%)	Specific Gravity	Classification
GMW3A	4.5-5.5	0.7	51.0	25.0	2.7	CL
GMW4	2.0-4.0	---	26.9	N/P	---	ML
GMW4	4.0-5.2	---	32.6	N/P	---	ML
GMW5	6.0-8.0	---	27.0	35.8	---	CL
GMW5	14.0-16.0	---	30.8	N/P	---	ML
GMW9	9.0-9.5	---	32.1	52.1	---	CL
GMW9	12.5-13.0	---	19.6	N/P	---	ML
GMW10	8.5-9.0	---	24.6	34.5	---	SC
GMW10	16.0-16.7	0.4	33.0	17.0	2.6	SC
GMW13	12.0-14.0	1.0	51.0	28.0	2.7	MH
GMW14	16.0-17.2	0.5	35.0	16.0	2.6	SC
	Depth(in)					
B18	20-20.5	---	50.8	80.0	---	CH
BS	18-24	---	21.1	28.7	---	CL
CS	52-57	---	45.6	N/P	---	ML
HS	48-59	---	21.6	33.5	---	CL
I	19-24	---	29.9	28.1	---	CL
I	34-39	---	33.8	36.8	---	SM
JS	68-70	---	32.0	N/P	---	ML
L	17-23	---	34.6	44.6	---	CL
L	33-38	---	35.1	39.6	---	ML
MS	24-29	---	20.1	27.6	---	CL
MS	41-46	---	36.0	N/P	---	SM
NS	32-35	---	15.4	N/P	---	ML
NS	48-53	---	18.7	23.7	---	CL-ML
NS	60-65	---	24.9	N/P	---	ML

Table 3 - Soil engineering properties measured on split spoon and shelby tube samples.

to 50%. The void ratio is between 45 and 50%, and the specific gravity of the material varies from 2.6 to 2.7.

The weathered granite is overlain unconformably by regressive fluvial sediments. These sediments consist mainly of reworked granite residium and disintegrated granite, that traveled only a short distance before being redeposited. These sediments are yellowish-brown to reddish-brown fine to coarse sand and clay, often mottled with iron oxide, showing no discernable depositional structure. The fine to coarse sand fraction varies from 30 to 40%, the silt fraction varies from 20 to 25%, and the clay fraction varies from 35 to 45%. Weathering has produced thin sand seams (SM type soils) in some areas within the unit, with orientations varying from horizontal to vertical. The regressive fluvial sediments are also ML and CL type soils according to the Unified Soil Classification System. The plasiticity index ranges from non-plastic to 10%, and the liquid limit ranges from 15 to 20%.

At the top of the regressive unit, a friable clayey sand, or in some areas a hardpan consisting of loosely cemented sand, has developed. The development of the hardpan appears to coincide with the presence of the Colfax fine sandy loam unit shown on the soils map (Figure 4). This hardpan grades laterally into a hard, friable, clayey sand in areas where the Pouncey sandy loam and the Kempsville very fine sandy loam are present. The hardpan or friable clayey sand layer restricts vertical ground-water movement over much of the area, causing a shallow perched water table within the regressive fluvial sediments. In some areas the hardpan layer is dry, even though overlain by several feet of saturated sediment. Plate 3 shows the elevation of the top of the hardpan, or friable clayey sand unit. The positions of the soil units coinciding with the relative development of cementation within the layer are shown in Figure 4. In some areas on-site, specifically the covered holding lagoon and the concrete holding pond shown on Figure 2, the friable clayey sand has probably been penetrated by excavation. Also, in the areas where standing water is present, shown on Plate 2, and near North Run Creek, the friable clayey sand is either poorly developed or absent. The occurrence or absence of the hardpan, or friable clayey sand unit, controls the hydraulic relationship between the shallow perched water table and the weathered granite aquifer.

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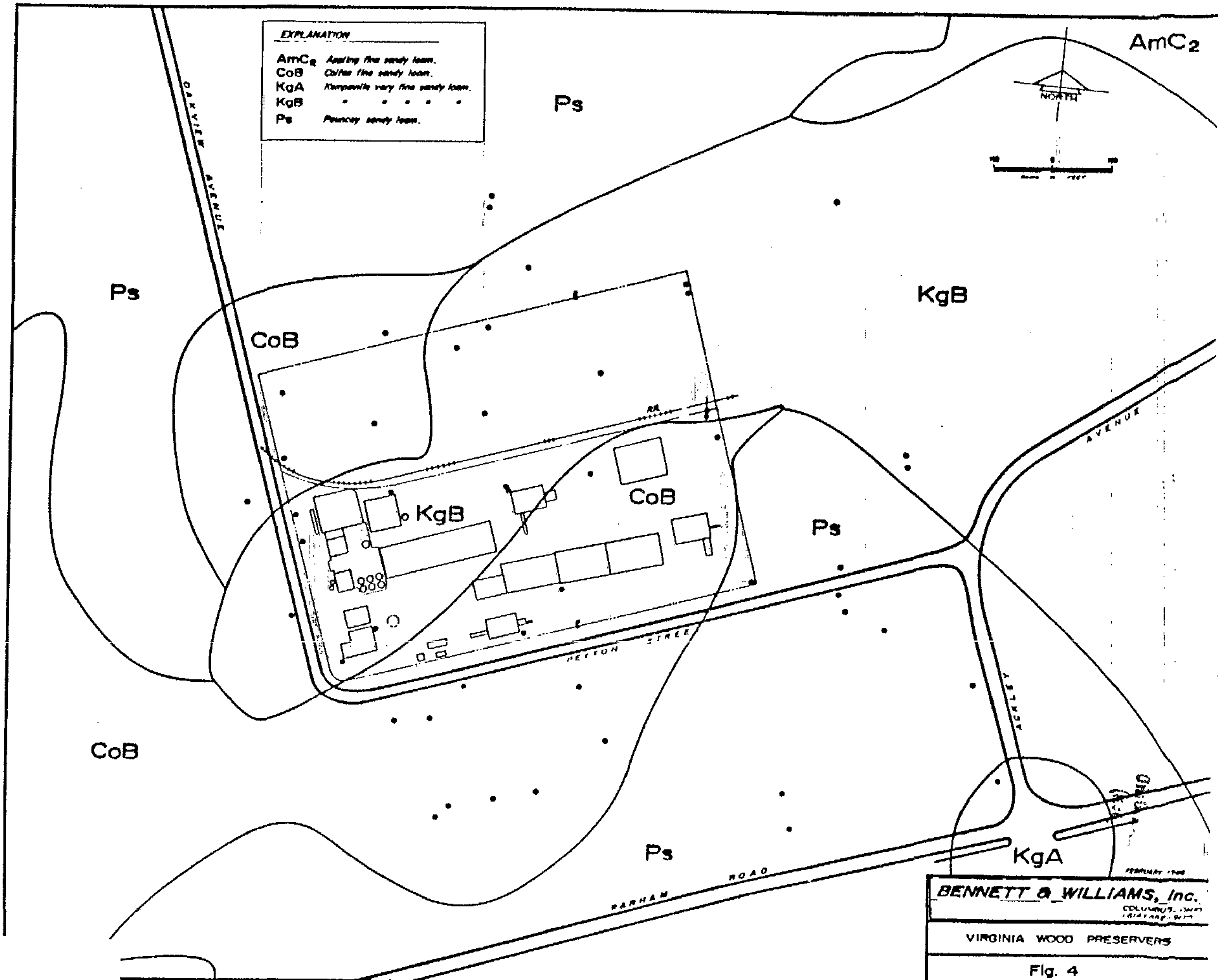
The hardpan and friable clayey sand layer is classified as SM and ML type soil according the the Unified Soil Classification System. The plasticity index ranges from non-plastic to 10%, and the liquid limit ranges from 30 to 40%.

Soils which have developed on the regressive fluvial sediments are identified in Figure 4 (modified from Clay, 1975). The Colfax fine sandy loam (CoB) is a poorly drained soil on level to gentle slopes. This soil, and the other soils present, are characterized by a 0.5 to 4.5 foot sandy clay underlain by a clayey sand. The Colfax fine sandy clay loam is distinguished by the low amount of runoff, and the presence of a hardpan, exhibiting cementation, at the base of the soil profile. The Pouncy soil, as identified by the Soil Conservation Service, is a poorly drained Colfax series soil with a clay substratum that varies from friable to very loosely cemented. The Kempsville fine sandy loam is a well drained soil on gentle to steep slopes. Runoff is medium, and a friable clayey sand layer is present.


EXPLANATION
AmC2 Appling fine sandy loam.
CoB Colfax fine sandy loam.
KgA Kempsville very fine sandy loam.
KgB " " " " "
Ps Pouncey sandy loam.
NORTH
OAKVIEW AVENUE
AVENUE
ACKLEY
PEYTON STREET
PARHAM ROAD
RR
Ps
CoB
KgB
AmC2
KgA
BENNETT & WILLIAMS, Inc.
VIRGINIA WOOD PRESERVERS
Fig. 4

HYDROGEOLOGY OF THE SITE

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The Petersburg granite is a highly fractured, confined aquifer. Deep wells on-site, shown as D1 and D2 on Plate 2, were drilled to depths of 425.6 and 244.6 feet, respectively. Fracture trends within the unit tend to be either very steep or horizontal, therefore it is quite likely that the wells produce from the same fracture system.

Because of probable interconnection with the shallow weathered granite aquifer, caused by leakage around the well casing, static water levels recorded in wells D1 and D2 are suspect. On April 26, 1985, static water level was 5.7 feet below the surface (206.5 feet amsl) in D2, and 7.42 feet below the surface (205.8 feet amsl) in D1. The water level in D1 was at least 150 feet below the surface after pumping at 7 gpm for approximately 136 hours, and the water level in D2 was only 34.5 feet below the surface after being pumped at the same rate for 112 hours. This may indicate that the deep wells are screened in fracture zones of variable frequency and interconnection. It could also be caused by a casing leak, however, allowing cross-connection with the weathered granite aquifer in well D2. Casing leakage may be the cause of shallow static water levels in D1 as well.

Shallow water bearing units at the site consist of a four to ten foot layer of the regressive fluvial clayey sands unconformably underlain by severely weathered granite. At the base of the regressive fluvial sediments, a friable clayey sand or hardpan is present, upon which a shallow perched water table develops. The weathered granite has a lower permeability than the overlying regressive fluvial sediments, and is semi-confined by the hardpan.

The hardpan, or friable clayey sand equivalent, at the base of the regressive fluvial sediments, exerts a dominant influence on ground-water flow in the unconsolidated sediments overlying the granite. The hydraulic relationship between the shallow perched water table and the semi-confined weathered granite aquifer depends on the permeability and thickness of the hardpan or friable clayey sand. The permeablility and thickness of this unit vary considerably across the site, and are related to the soil types shown on Figure 4. In areas of the Colfax fine sandy loam, a very hard, cemented hardpan from 1.5 to 7.5 feet thick restricts vertical ground-water movement. Borings that penetrated to the weathered granite aquifer in these areas encountered saturated sediments above the hardpan, and confined conditions below the hardpan; however, the hardpan sediments were dry. The friable clayey sand associated with the Pouncey sandy loam and the Kempsville very fine sandy loam is typically weakly-cemented, and borings penetrating into this unit encountered moist to dry conditions. Near North Run Creek, and within the areas containing standing surface water, saturated conditions were encountered in this unit, indicating that vertical percolation does occur. However, the permeability of the hardpan in these areas is much lower than the sediments above and below, so that piezometric levels above and below are interconnected, but not necessarily equal.

The weathered granite aquifer underlying the hardpan or friable clayey sand unit provides ground water for local shallow water wells in the area. Depth to the unit varies from 4.5 to 14.0 feet below the ground surface, and the thickness varies from 3.6 to 30.0 feet. Based on laboratory and in-situ permeability tests, and thicknesses encountered in wells and borings, transmissivities within the unit vary from 2 to 12 gpd/ft (0.003 to 0.02 cm^2/sec). The transmissivity data is normally distributed (Kolmogorov-Smirnov statistic = 0.201; significance = 0.197), and based on a Student's t-test, can be approximated by a mean value of 9.2 gpd/ft (0.013 cm^2/sec) with a standard deviation of 4.5 gpd/ft (0.0065 cm^2/sec). Table 4 shows values obtained by laboratory and in-situ permeability tests.

Plate 4 shows a potentiometric surface contour map constructed from piezometric levels measured on January 30, 1986, in monitoring wells screened within the weathered granite. Piezometric levels within the aquifer are generally above the bottom of the overlying hardpan or friable clayey sand layer, indicating confined conditions. Ground water flows north and northwest across the site at gradients varying from 0.003 to 0.007 ft/ft, with gradients increasing to 0.01 ft/ft near North Run Creek. A ground-water divide trends along Parham Road south of the site. North of this divide, ground water flows across the site and into North Run Creek, and south of the divide, ground water

Table 4 - Values of hydraulic conductivity, and transmissivity, measured by in-situ well tests, and laboratory analysis on undisturbed soil samples.

Well/Screened interval (depth ft)	In-situ hydraulic conductivity	In-situ transmissivity
	gpd/sq ft	gpd/ft
GMW2/8-18.1	1.17	11.90
GMW3/15-20.4	0.52	6.40
GMW3A/19-25.7	5.90	16.30
GMW5/4.8-7.1	0.88	8.82
GMW10/11.8-18..8	0.63	7.90
Well no./depth(ft)	Labratory hydraulic conductivity	
	gpd/sq ft	
GMW3A/4.5-5.5	0.47	
GMW10/16.0-16.7	0.02	
GMW13/12.0-14.0	0.23	
GMW14/16.0-17.2	0.07	

flows southward toward another tributary of North Run Creek. The ground-water divide deviates from Parham Road in the area of standing water southeast of the site. In this area, the friable clayey sand unit is saturated and has a higher permeability than the majority of the restrictive unit. This has resulted in ground-water discharge at the ground surface, and the standing water is apparently an expression of the piezometric levels within the weathered granite. A similar condition occurs north of the site near North Run Creek, resulting in ground-water discharge to the stream.

The potentiometric surface of the shallow perched water table in the sediments overlying the weathered granite aquifer is extremely sensitive to recharge through infiltration. The depth of the water table varies from 0.0 to 4.6 feet below the surface, and saturated thickness varies from 0.0 to 7.4 feet. The hydraulic conductivity of the unit, based on laboratory and in-situ permeability tests, varies from 0.2 to 2.0 gpd/ft^2 (9.4×10^{-6} to 9.4×10^{-5} cm/sec), and averages 1.3 gpd/ft (6.1×10^{-5} cm/sec). These values correspond with infiltration rates for the soils present, reported by Clark, 1975.

Plate 5 shows a potentiometric surface contour map constructed from water levels measured on January 30, 1986, in monitoring wells and screened borings, screened above the bottom of the regressive fluvial sediments. Ground-water flows north and northwest across the site, except in areas within the standing water environs, where mounding in the shallow perched water table causes flow directions to deviate to the east and west. Ground-water gradients vary from 0.003 to 0.02 ft/ft, and average 0.01 ft/ft. A ground-water divide is evident south of the site, trending along Parham Road. Ground-water mounding in the southeast portion of the study area causes ground water in the shallow perched water table to flow south across Parham Road. Ground-water from the shallow perched water table discharges into the stream to the north of the site.

On January 30, 1986, when the water levels used to construct Plate 5 were measured, the potentiometric surface in the shallow perched water table was higher than the potentiometric surface in the weathered granite aquifer in the western portion of the study area and around the areas of standing water. This area is designated as Zone A on Plate 5. Zone B represents the area where the potentiometric surface in the shallow perched water table was lower than the potentiometric surface in the weathered granite. The boundaries between Zone A and Zone B, shown by the heavy lines on Plate 5, represent the intersection of equal equipotential lines within the shallow perched water table and the weathered granite aquifer.

In Zone A, the restriction of vertical gound-water movement by the hardpan or friable clayey sand causes ground-water to flow horizontally along the base of the regressive fluvial sediments. Over the southern portion of the Virginia Wood Preserving Corporation property, the regressive fluvial sediments were unsaturated on January 30, 1986, resulting in the apparent flattening of flow gradients shown on Plate 5. This condition has resulted from a lack of recharge from infiltration of rainwaters, and discharge through the shallow perched water table is essentially zero.

In the areas of standing water, shown on Plate 2, and near North Run Creek, recharge and discharge of the weathered granite aquifer occurs in response to the relative positions of the potentiometric surface elevations in the two aquifers. In these areas there is a relative increase in the permeability and decrease in the thickness, or the absence, of the friable clayey sand unit. Where these conditions are present, vertical ground-water movement is not as restricted as in other areas, where the hardpan or friable clayey sand unit is well developed. When the potentiometric level in the shallow perched water table is higher than that of the weathered granite, recharge of the weathered granite occurs at a rate commensurate with the vertical conductivity of the friable clayey sand unit. When the potentiometric surface in the shallow perched water table is lower than that of the weathered granite, the weathered granite aquifer discharges water upward into the shallow perched water table.

Water levels measured in November and December, 1985, shown in Table 5, and field observations of saturated conditions during the installation of borings BS through NS during the first two weeks of November, indicate that the elevation of the shallow perched water table during this period was higher than the elevation of the top of the hardpan or friable clayey sand. This implies that when sufficient recharge of precipitation is available, ground-water discharge throughout the shallow perched water table occurs, and the potentiometric surface in the shallow perched water table is greater than the potentiometric surface in the weathered granite.

On January 30, 1986, the weathered granite aquifer was apparently discharging ground-water into the shallow perched water table within the Zone B area just west of the area of standing water southeast of the site. This resulted in an influx of water into the area of standing water, and a corresponding decrease in the potentiometric surface of the weathered granite aquifer. This condition also resulted in an influx of water into the more permeable fluvial regressive sediments, thereby creating the circular ground-water mound surrounding the areas of standing water.

Table 5 – Static water levels measured in monitoring wells. Upper table is water levels within the weathered granite aquifer. Lower table is water levels in the shallow perched water table aquifer.

WELL NO.	SURFACE ELEV.	WATER LEVEL 11/21/85	WATER LEVEL 1/30/86
1	208.8	206.4	206.0
2	208.0	203.9	204.0
3	209.1	205.5	205.2
4	209.0	205.3	204.3
5	213.5	207.4	207.0
6	212.0	210.5	209.8
7	210.0	207.5	207.8
8	207.1	207.1	207.1
9	207.5	205.8	205.4
10	210.4	205.6	205.1
11	202.0	199.6	200.8
12	209.4	201.8	202.1
13	207.8	208.1	206.4
14	213.0	206.1	205.8

WELL/BORING	SURFACE ELEV.	WATER LEVEL 11/21/85	WATER LEVEL 1/30/86
2A	208.0	206.4	204.9
3A	209.1	206.6	205.3
9A	207.5	206.6	204.3
10A	210.4	208.1	209.1
11A	202.0	201.9	197.7
B	210.4		206.1
C	210.2		205.9
D	207.8		203.5
E	208.0		203.7
F	207.5		204.0
H	209.7		205.4
J	205.5		201.2
K	213.1		208.8
M	206.2		201.9
N	209.5		205.2

THREE-DIMENSIONAL GROUND-WATER FLOW MODEL

A ground-water flow model of the study area was developed from geologic and hydrogeologic data obtained during this investigation. The USGS modular three-dimensional finite-difference ground-water flow model computer program was used (McDonald, and Harbaugh, 1984). Calibration was acheived by selectively modifying hydraulic coefficients and flow characteristics until the model-generated potentiometric surface of the shallow perched water table and weathered granite aquifer approximated the observed levels measured on November 21, 1985, and January 30, 1986. Model boundaries and nodal designations are shown in Plate 6.

The hydrogeologic data used to develop the model, and the model output is shown in Appendix 3, along with an explanation of the various data matrices used. The model output indicated that aquifer boundaries, as shown on Plates 4 and 5, are correctly located. It appears that ground water, discharging upward from the weathered granite aquifer, is entering North Run Creek, and that the weathered granite aquifer and the shallow perched water table are hydraulically continuous in this area.

The ground-water flow model indicates that discharge through the modeled area is approximately 520 gpd. Of this, discharge through the Virginia Wood Preserving Corporation site is estimated to be 135 gpd. Volumetric budget error for the model is 1.09 gpd.

Although calibration was acheived using water levels measured on November 21, 1985, and January 30, 1986, the model can be used to simulate various precipitation events, and corresponding water level fluctuations. In addition, ground-water flow directions, and gradients, induced by alternate pumping rates and pumping well orientations can be simulated in an attempt to identify the most efficient, and cost-effective system for recovering contaminated ground water.

EVALUATION OF MONITORING WELL CONSTRUCTION

Construction of monitoring wells 1, 2, 3, 4, and 5, installed during a previous investigation at the site, may allow cross-contamination of ground water from the shallow perched water table into the weathered granite aquifer. Construction of these wells involved hollow stem augering, with augers that were not cleaned prior to each use. Prior to setting the PVC screen and casing, augers were removed from the boring, thereby allowing contaminated surface sediments into the screened zone below. After setting the screen and casing, the portion of the screened zone that had not caved was packed with pea gravel. Above this, potentially contaminated surface soils, mixed with dry bentonite powder, was placed to within a few feet of the surface. This backfill material probably does not have sufficient consistency, or impermeability, to provide a good seal around the well casing. Because organic compounds are adsorbed on the PVC materials, and because of the slow release of the contaminants from the PVC, even if contaminant levels in the ground water around these wells were reduced to non-detectable levels, samples collected from these wells may nevertheless show trace organic contamination.

Because of the potential for cross-contamination, and the limited usefulness of these wells in monitoring water quality within the subsurface formations, it is recommended that these wells be removed and properly plugged.

Replacement wells should be drilled using appropriate drilling methods and materials. Wells 6 and 7, also constructed of PVC screen and casing, should be developed and sampled. If organic contaminants are detected, then these wells should also be removed, properly plugged, and abandoned.

Stainless steel screen and casing materials were used in the wells installed during this investigation to avoid the accumulation of organic compounds not representative of ground-water quality. The screen and casing, and the materials used to backfill, were placed in the boring at six inch intervals as the auger stem was raised. Sand pack material was chosen on the basis of screen size, and consisted of filtered silica sand. A layer of expandable bentonite pellets was placed directly above the sand pack, and bentonite slurry was used to backfill to the surface.

Because of the use of bentonite pellets and slurry in the monitoring wells, certain chemical parameters, including COD, sulfate, dissolved oxygen, and chloride, may temporarily exhibit elevated concentrations until the wells are fully developed. Values of alkalinity and total hardness also may be temporarily reduced (Brobst and Buszha, 1986).

The borings designated with an "S" following a letter (for example, boring BS) have PVC slotted screens and casing, surrounded with sand pack, and backfilled with bentonite pellets. These borings were screened for observing the shallow perched water table and the non-aqueous phase liquids, and are not intended for ground-water monitoring. The screen and casing should be removed, and borings plugged, when observations are complete.

The deep water wells, designated as D1 and D2 on the site location map, were drilled some time ago, and boring logs could not be located. The depth of D1 is 425.6 ft, and the depth of D2 is 244.6 ft. The depth of surface casing in these holes is not known. Because static water levels in the wells are similar to water levels in the weathered granite aquifer, either leakage of ground water from the weathered granite into the wells is occurring, or the weathered granite and granite aquifers are hydraulically connected through fractured zones. In either case, monitoring of water quality in the granite aquifer is required. As discussed previously, prolonged pumping of well D2 indicated that ground water from the weathered granite may have discharged into the deep well at rates consistent with a casing leak or break. Pumping of well D1 indicated that ground-water discharge from the weathered granite into the deep well probably occurs at much lower levels.

Chemical analysis of samples collected from these wells, shown in Table 8, indicate that organic compounds were present in well D2. To evaluate whether cross-connection, or hydraulic interconnection, with the weathered granite has contaminated the Petersburg granite aquifer, it is recommended that three deep monitoring wells be installed in locations shown on Plate 8. Special care should be taken in drilling and constructing these monitoring wells to prevent cross-connections, and prevent contamination during drilling. If cross-connection between the weathered granite aquifer and the Petersburg granite aquifer is responsible for the contaminant concentrations detected in water samples from these wells, the casings of wells D1 and D2 should be removed and the wells properly plugged.

In the past, creosote and pentachlorophenol-based wood preservative formulations have been used to treat lumber at the Virginia Wood Preserving Corporation site. At present, CCA (copper, chromium, and arsenic oxides) solution is being used. Based on the chemical analyses available at this time, it appears that creosote, pentachlorophenol, and CCA have entered the soil and ground-water environments. Data is not available to evaluate any potential contamination by CZA, No. 2 fuel oil or xylene formulations.

Field observations have indicated that three phases of contaminant, which will require separate consideration from an investigative and remedial standpoint, are present at the site. The first of these phases is a light non-aqueous phase liquid, present within the unsaturated (vadose) zone and within pore spaces in the upper portion of the saturated zone. The second phase is a dense, immiscible liquid present within the saturated zone. A third phase of contamination consists of dissolved organic and metal constituents within the saturated zone.

Chemical analyses of the organic compounds in the various phases have not been completed. Based on previous investigations and research on similar creosote and pentachlorophenol formulations, certain postulations can be made regarding the organic compounds present within each phase.

Creosote is a complex mixture of chemical compounds consisting of as much as 85% polynuclear aromatic hydrocarbons, and up to 17% phenolics. Other compounds consist of numerous nitrogen and sulfur containing heterocyclic compounds (U.S Forest Products Lab., 1974). When mixed with water, creosote has been known to separate into two distinct phases: the phenolics, being fairly soluble (on the order of 10 gm/l) form a light aqueous phase, and the polynuclear aromatic hydrocarbons, being slightly soluble to insoluble (on the order of 0.032 gm/l) form an immiscible hydrocarbon phase. Although some of the polynuclear aromatic hydrocarbons in creosote (such as phenanthrene), as well as many of the phenolic compounds, are less dense than water, many of the polynuclear aromatic hydrocarbons present in creosote (such as napthalene, acenaphthene, and carbazole), as well as pentachlorophenol and many of the phenolic compounds, are more dense than water. Therefore, it is theoretically possible for an immiscible hydrocarbon phase, formed from creosote, to further separate into phases that are lighter than water, and heavier than water.

Before discussing the distribution of contaminants at the Virginia Wood Preserving Corporation site, it is helpful to review some of the principals governing the occurrence and migration of non-aqueous phase liquids. An in-depth presentation of theoretical concepts is presented in several texts describing two-phase immiscible flow, and is substantially beyond the scope of this report. Our

AR100321 discussion is limited therefore to summarizing some of the general principles involved in evaluations of immiscible liquid migration and recovery.

Interfacial Tension

The ability of two immiscible fluids to flow through the same porous medium is largely dependent on the interfacial tension between the two fluids. Interfacial tension reflects the net inward attraction of fluid molecules in contact with another fluid. In the case of a liquid in contact with air, the term surface tension is commonly used to describe the same forces. The interfacial tension between the non-aqueous phase liquids encourages the immiscible liquids to form droplets within the water. These droplets have greater difficulty squeezing through the interconnections between pore openings, such that the droplets are often retained within the pores.

The inter-relationship between interfacial tension and capillary openings is demonstrated by the formula:

$$Pc = 2\ T\ \cos\ /r$$

where Pc is capillary pressure, T is interfacial tension, and r is the radius of the capillary opening. Although more complicated equations involving pore aspect geometry are normally used for definitive computations, this general equation correctly illustrates the relationship between the various terms. The greater the capillary pressure, the more difficult it is to squeeze immiscible liquid droplets through the soil. It is evident that capillary pressure will increase as the interfacial tension between the liquids increases, and as the size of capillary openings is reduced.

The cos term is a measure of the wetting tendencies of the two fluids. Under most normal circumstances, water is the wetting fluid. Although the angle of wettability is almost impossible to accurately measure in a porous soil material, with water as the wetting fluid it is common to assume an angle of zero, for which cos equals one. Research has shown that slight deviations from this assumption in most field situations have little influence on the correct interpretation of forces acting on the immiscible liquids.

Although the components comprising the non-aqueous phase liquids at the site are not known at this time, it is probably accurate to assume a surface tension between water and the non-aqueous phase liquids between 44.2 (interfacial tension between napthalene and water) and 33.1 dynes/cm (interfacial tension between phenols and water). For the purposes of discussion, values for the interfacial tension between water and air (surface tension) and water and the non-aqueous phase liquids are assumed to be 73 and 35 dynes/cm, respectively.

Residual Saturation

Residual saturation is commonly described as the irreducible quantity of immiscible liquid, retained in pore openings, that cannot be removed from the soil by flushing. It is usually expressed in terms of percentage of total porosity. The concept of irreducibility is not totally correct, and often causes misunderstandings. It is more appropriate to say that, for any given set of conditions, a point of diminishing recovery will be approached.

Residual saturation is inter-related with realtive permeability. As a general rule, relative permeability of sediments to immiscible fluids approaches zero as their saturation decreases to about 15% of pore volume. This value will vary with pore size and liquid characteristics, within a reasonable range of plus or minus 5%.

It is also important to note that this concept of irreducible saturation similarly applies to soil water. The minimum residual saturation of water in the presence of immiscible liquids is commonly assumed to be about 20% of pore volume. Therefore, even in zones of free-flowing immiscible liquid, where the relative permeability of the soil to water may be 10% or less, water saturations of one-third to one-half the pore volume would not be uncommon. Calculations of immiscible liquid quantities in soil that fail to recognize the partial occupation by water may seriously overestimate the actual volume of immiscible liquid.

Immiscible Liquid Stringers

Interfacial tension causes droplets of light immiscible liquid to snap-off within the soil pores, where they are prevented from further migration. The gradient of water flow across a single pore is normally not sufficient to overcome the capillary pressures resisting the squeezing of the immiscible liquid drop through the capillary opening. If the immiscible liquid droplets agglomerate into strings, however, capillary pressures at each end remain the same, but now an additional flow gradient will be pushing against the stringer. At some length, relative to the soil's particular pore aspect geometry, the stringer will begin to move.

For stringers in the vertical orientaion, bouyancy is the driving force. For stringers in the horizontal orientation, ground-water flow provides the driving force. The process is intermittent, as the stringer breaks, agglomerates with new droplets, and moves again. But it is easy to see that the more continuous the light immiscible liquid is, the more likely it will be to migrate. Conversely, irregular and isolated immiscible liquid droplets, in heterogeneous materials, will be difficult if not impossible to move.

Threshold Gradient

Residual immiscible liquids are not irreducible, but can be mobilized by increasing hydraulic gradients above a threshold value. This threshold gradient can be evaluated in terms of the Capillary Number, Nc, a dimensionless ratio of capillary forces to viscous forces.

The minimum capillary number for initiating residual immiscible liquid movement is approximately 2 x 10 (Wilson and Conrad, 1984). For an interfacial tension of 35 dynes/cm, and the average hydraulic conductivity of soils at the Virginia Wood Preserving Corporation site, the critical hydraulic gradient for mobilizing the immiscible liquids is 227. Likewise, the gradients required for removing 50% and 100% of the immiscible liquid residual are determined to be 3410 and 14,800, respectively.

In unconfined aquifers, the maximum hydraulic gradient that can be obtained is 1.0, such as experienced during gravity flow. This is less than 0.5% of the minimum gradient required for blob mobilization. Hydraulic gradients could be artificially increased to 227 only by enormous ponding of water above the ground surface or by injecting water at excessively high pressures. Obviously, neither of these two artificial procedures are practical in this instance. It is thus apparent that, aside from areas where free-flowing immiscible liquids are present, recovery of residual immiscible liquid by pumping and water-drive methods will not be successful.

Thickness of the Non-Aqueous Phase Liquids

In most field investigations of non-aqueous phase liquid contamination, estimates of the quantity of immiscible liquid in the ground are usually requested. However, these estimates are seldom reliable, because it is extremely difficult to measure the thickness of the non-aqueous phase liquids in the ground. It is well known that the thickness of light immiscible liquids, which exist in the unsaturated zone and in the upper portion of the saturated zone, measured in a well, is not representative of the actual thickness in the ground. Although many equations and theories have been proposed for quantifying the relationship between thickness in the ground and in wells, none of these equations consistently apply to field conditions. A useful approximation is often used, wherein the thickness of the light immiscible liquids in a well is assumed to be two to four times greater than the thickness of the immiscible liquid in the formation. Since more detailed computations often fail to provide more useful answers, this may be the most useful first approximation in lieu of more definitive field data.

As non-aqueous phase liquids migrate downward through soil materials above the ground water surface, some of the immiscible liquid is retained by the soil paricles, while the remainder continues downward. If the supply of non-aqueous phase liquids exceeds this retention capacity, the liquids will eventually migrate down to the top of the ground-water surface. Immiscible liquids which are lighter than water will spread through the capillary zone, while dense immiscible liquids will move through the saturated zone in a manner dependent on the capillary pressure, gravitational forces, and viscous forces, as discussed previously. The capillary zone is the partially saturated section of the soil above the free water table, where water is held by capillary forces at below atmospheric pressures. As shown by the preceding equation for capillary pressure, the smaller the radius of the capillary tube, the greater

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will be the capillary pressure and the height to which the immiscible liquid will rise. In a heterogeneous soil composed of variable particle and pore sizes, the height of rise and relative liquid saturation will vary. Thus, some tubes will be completely saturated while other adjoining portions will be only partially saturated, even at lower levels.

This concept is critical for understanding the thickness of light immiscible liquids in wells. Immiscible liquids will flow more readily through those portions of the capillary zone where water saturation is reduced. At lower portions of the capillary zone, where water saturation will be 70% or more, immiscible liquids will move very slowly if at all. On the other hand, near the top of the capillary zone, where water saturations are 30% or less, the immiscible liquids may move rather freely. Based on recent research, the thickness of free-flowing, light immiscible liquid at the top of the capillary fringe in the clayey fine to medium sands present at the site could reach between two and ten inches, assuming saturation of non-aqueous liquid.

When this free-flowing light immiscible liquid reaches the well, therefore, its position at the top of the capillary zone is above the free water surface in the well. As the immiscible liquid flows into the well, it fills between these two levels. The greater the height of the capillary zone, the greater the thickness of immiscible liquid in the well.

Rather than measuring the thickness of a light immiscible liquid in the well, it is usually more meaningful to evaluate the presence of the liquid in soil samples. This can be used in conjunction with determinations of capillary zone characteristics, to estimate the actual thickness of soil through which light immiscible liquids flow.

Refraction of Flow Paths

There is one final consideration before describing the distribution of immiscible liquids at the site, and that is the refraction of flow paths caused by variations in hydraulic conductivity. An illustration of how this occurs is shown in Figure 5. Note that the flow lines are refracted twice, at each change of material. As shown in Figure 5, this refraction follows the relationship,

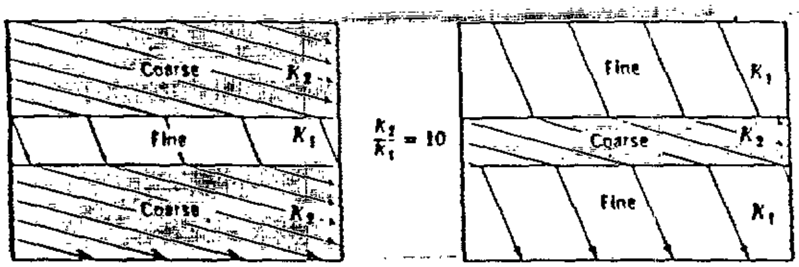
$$\frac{K_1}{K_2} \quad \frac{\tan O_1}{\tan O_2}$$

where: K_1 is the permeability of layer 1,

K_2 is the permeability of layer 2,

O_1 and O_2 are angles of refraction.

This principle is useful for visualizing the flow of ground water and the immiscible liquids in the fluvial regressive sediments and the associated hardpan and friable clayey sand layer at the Virginia Wood Preserving Corporation site. In particular, the conditions shown in the K2 > K1 illustration in Figure 5 is similar to ground-water flow conditions within the shallow perched water



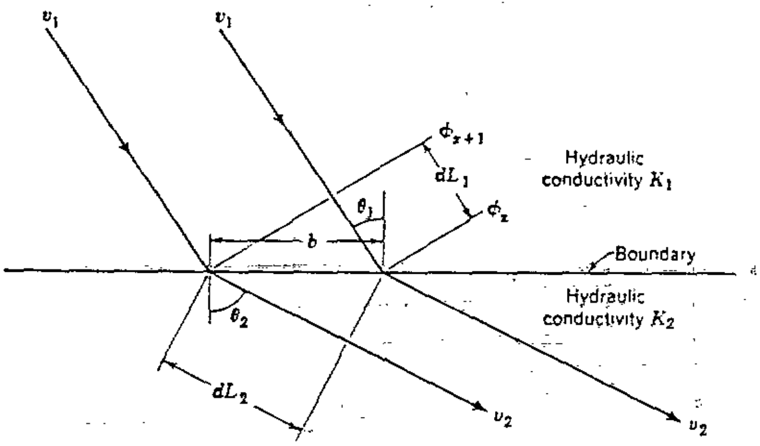


Fig. 5 - Refraction of flow lines across a boundary between media of different hydraulic conductivities (from Todd, 1980).

table. At the Virginia Wood Preserving Corporation site, the ratio of K2/K1 probably varies from ten to infinity (infinity representing no flow through the hardpan). In the region where immiscible liquids have been detected, K2/K1 is approximately 100. Ground water and dense immiscible liquids will flow preferentially through the clayey sands of the regressive fluvial aquifer overlying the less permeable restrictive hardpan.

The decrease in pore size associated with the restrictive friable clayey sand layer also has an important effect on migration of the dense immiscible liquid. As the liquid moves vertically under the force of gravity, it is influenced by capillary pressure, and the force exerted by the flow gradient. Figure 6 illustrates the various effects of the forces at work on the immiscible liquids, and the resulting theoretical distribution of the non-aqueous phase liquids. When a dense immiscible liquid encounters a layer of low permeability, and the associated decrease in pore size, the capillary pressure is increased (Pc 1/r), and unless the vertical gradient is much greater than the horizontal gradient, the low permeability layer will serve as a barrier to the immiscible liquid.

Figure 6 - Distribution of non-aqueous phase liquids in the shallow perched water table aquifer.

SATURATION	LIQUID PHASE	SOILS
WATER<30%	FREE-FLOWING LIGHT IMMISCIBLE LIQUIDS	SANDY CLAY
CAPILLARY ZONE WATER > 70%	RESIDUAL LIGHT IMMISCIBLE LIQUID	
WATER TABLE WATER = 100%	GROUND WATER WITH DISSOLVED ORGANICS (AQUEOUS PHASE)	CLAYEY SAND
WATER > 85%	GROUND WATER WITH RESIDUAL DENSE IMMISCIBLE LIQUID	
85% > WATER > 15%	DENSE IMMISCIBLE LIQUID AND "RESIDUAL" GROUND WATER	
CHANGE IN POROSITY	GROUND WATER WITH DISSOLVED ORGANICS (AQUEOUS PHASE)	HARDPAN

The history of operations for the Virginia Wood Preserving Corporation site identifies several possible sources of contaminant. The most obvious sources of contaminant on-site are the covered holding lagoon, and the area of the blow-down sump prior to its removal. When referring to the sources of contamination in this report, the blow-down sump encompasses the entire area around the concrete holding pond, constructed over the blow-down sump. This is meant to avoid any confusion which may result from referring to the blow-down sump, which is not shown on the site location map, and is not meant to infer that the holding pond itself is the source of contamination. Other sources of contamination are run-off and seepage of wood preserving formulations used in the treatment process, and surface run-off of contaminanted water.

The non-aqueous phase liquids, which probably originated from the covered holding lagoon and the area around the holding pond, appear to be restricted to the shallow perched water table on-site. These contaminants provide a constant source of aqueous contaminants to ground water, through slow dissolution of the organic compounds into the aqueous phase.

Water samples, collected from the covered holding lagoon in April, 1985, contained creosote concentrations varying from 30 to 5659 ug/l, and pentachlorophenol concentrations from 126 to 516 ug/l. A composite sample of soils taken from the covered holding lagoon contained a creosote concentration of 4923 ug/kg, and 4009 ug/kg pentachlorophenol. Copper, chromium, and arsenic concentrations indicating contamination were also detected. A soil sample collected from boring CS, near the holding pond, contained 4700 ug/kg total recoverable phenols.

Light Immiscible Liquid Contaminant

As discussed previously, the light non-aqueous phase liquid observed at the Virginia Wood Preserving Corporation site, is probably composed of those creosote parameters (such as phenanthrene) and phenolic compounds which are less dense than water. Based on our field observations of soil samples, the thicknesses of the highest concentrations of light immiscible liquids seemed to be on the order of four to six inches. The presence of light immiscible liquids was noted in boring FS, from 2.5 to 3.0 feet, boring CS, from 3.4 to 3.8 feet, and in monitoring well 3A.

Approximately 0.4 gallons of light immiscible liquid was recovered by pumping well 3A at a very low rate over a period of 24 minutes. The flow was more or less continuous at a pumping rate of 0.02 gpm. In an effort to examine the effects of increased hydraulic gradients on the migration of the light immiscible liquid, 3A was pumped again, at 0.33 gpm for 50 minutes, and pumped at variable levels to maintain unsaturated conditions around the shallow well for an additional 60 minutes. After 95 minutes, globules of light immiscible liquid were observed in the discharge line.

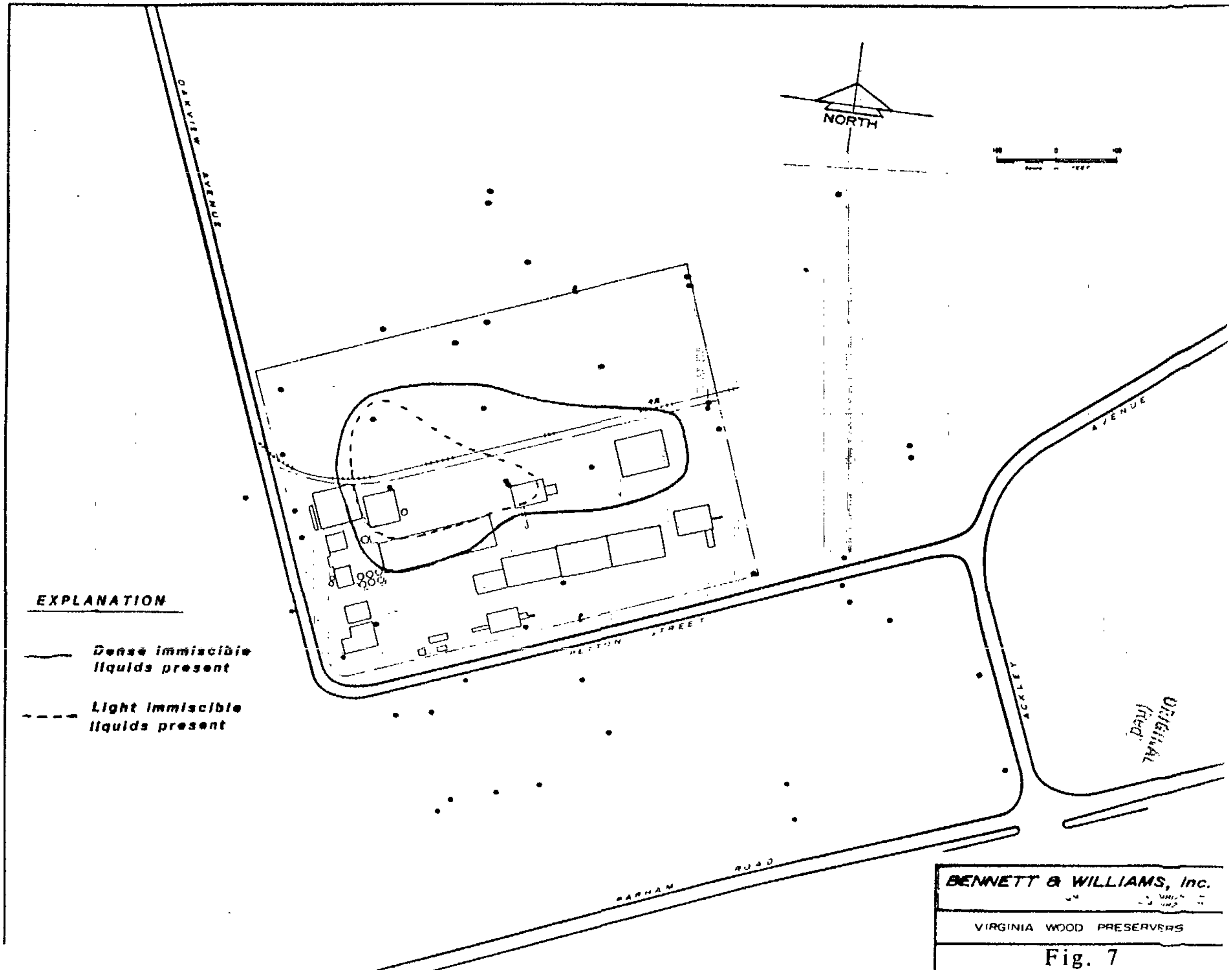
The approximate distribution of light immiscible liquid, based on field observations, is shown in Figure 7. An area of as much as 43,000 ft may have light immiscible liquids within the capillary zone. Assuming an average thickness of the light immiscible liquids of five inches, the total volume is calculated to be between 4000 and 20,000 gallons. Problems inherent in estimates such as this have been discussed previously. Of this volume, at least some of the soil must be above residual saturation because free-flowing immiscible liquid was observed in well 3A. However, an estimate of the amount of product which exceeds the soils retention capacity is premature until additional data on the characteristics of the soil and immiscible liquid has been acquired.

Dense Immiscible Liquid Contaminant

The dense immiscible liquid, observed in soil samples from several borings on the Virginia Wood Preserving Corporation site, is probably made up of compounds of creosote or pentachlorophenol, or a combination of the two formulations, which are more dense than water. As discussed previously, these immiscible liquids are present in the shallow perched water table, but probably can not readily migrate through the hardpan or friable clayey sand layer because of the restrictive pore sizes. In some areas, however, it is possible that the restrictive layer has been removed by excavation. Depth of excavation for the holding pond and the covered holding lagoon are not known. It may be possible for immiscible liquids to enter the restrictive layer in areas where the shallow perched water table is seasonally unsaturated. This appears to have occurred in boring GS, and may occur in the general area where water levels measured on January 30, 1986, indicated that the shallow zone was below the top of the friable clayey sand layer.

Dense immiscible liquids have been observed in soil samples from boring CS (from 3.9 to 6.0 ft), boring FS (from 4.5 to 5.3 feet), boring GS (from 3.7 to 8.0 feet), and well 3A (2.5 to 3.4 feet). Dry product residue was observed in boring DS (from 1.0 to 2.5 ft). In boring FS and well 3A, and in GS from 6.3 to 8.0 ft, product was visible in discrete pores. In boring CS and GS, free product was observed on the split spoon sample, and after the augers were pulled, free product was seen entering the boring.

Figure 7 shows the approximate boundaries of the dense immiscible liquid observed in soil samples. An area of as much as 134,000 ft may have dense immiscible liquids in pore spaces within the lower portion of the shallow perched water table. Saturation above the retention capacity, evidenced by free-flowing dense immiscible liquids seen in borings CS and GS, has probably been exceeded only in the regions surrounding the holding pond and the covered holding lagoon.



OAKVIEW AVENUE
NORTH
ACKLEY AVENUE
STREET
PARHAM ROAD
ORIGINAL (Red)
EXPLANATION
Dense immiscible liquids present
Light immiscible liquids present
BENNETT & WILLIAMS, Inc.
VIRGINIA WOOD PRESERVERS
Fig. 7

Original (Red)

Total Recoverable Phenol Concentrations in Soils

A total of 62 soil samples, from borings and wells, and from surface samples, were analyzed for total recoverable phenol concentration. Results are shown in Table 6. Concentrations varied from non-detectable to 47 mg/kg. Caution should be used in interpreting the analytical results shown in Table 6, as phenols occur naturally in the environment, as a byproduct of decomposition of organic materials. Background phenol concentrations probably range from 0.0 to 0.1 mg/kg over most of the site, and may be greater in samples collected near areas of standing water and at shallow depths in wooded areas. The problem of interpretation is further exacerbated by the fact that only a few grams of material, which may or may not be representative, are taken from each sample. Thus, the analytical technique, although precise, may not be representative or reproducible.

Figure 8 is a contour map of total recoverable phenol concentrations, measured in soil samples taken from depths of 0.0 to 2.0 ft. This map represents contamination of surface soil by contaminated runoff. Certain interpretations were required to complete the contours, particularly in the areas of standing water where samples were not collected. The placement of these contours has been modified from a strict honoring of the data points so that field observations, and related chemical analyses collected during previous investigations, could be incorporated in the interpretation. Data from boring DS,

Table 6 - Concentration of total recoverable phenols in soil samples. TRP stands for total recoverable phenols.

Boring or Well	Depth(in)	TRP(mg/kg)	Depth(in)	TRP(mg/kg)	Depth(in)	TRP(mg/kg)	Depth(in)	TRP(mg/kg)
A	6-12	0.13	24-30	<.08				
BS	24-30	<.15	44-48	<.14				
CS	41-46	1.6	57-62	16	70-75	47		
DS	6-12	<.16	17-22	<.08				
ES	12-18	0.13	38-44	<.08				
FS	24-29	0.41	48-53	0.25				
GS	35-40	4.6	63-68	7.5	78-82	13.5		
HS	16-22	0.11	29-34	<.08	39-44	0.08		
I	14-19	<.08	39-44	<.08				
JS	12-17	<.07	31-36	<.08				
KS	9-15	0.09	29-34	<.08	39-44	<.08	58-62	<.08
L	7-12	<.07	38-43	<.08				
MS	0-7	0.36	24-29	<.08				
NS	19-22	<.08	35-39	<.08	53-58	0.2		
Q	6-12	<.08						
S	6-12	<.08						
T	6-12	<.08						
U	6-12	<.08						
X	6-12	0.34						
GMW 2	0-2	0.09	2-4	<.08				
GMW 3A	6-12	<.08	24-30	<.08	36-42	0.1	48-54	0.18
GMW 6	6-12	<.08						
GMW 7	6-12	<.08						
GMW 8	6-12	<.08	24-30	<.08	42-48	<.08		
GMW 10	18-24	<.08	24-30	<.08	66-72	<.08		
GMW 11	6-12	0.14	24-30	<.08				
GMW 11A	6-12	<.08						
GMW 12	6-10	<.08	18-24	<.08				
GMW 13	6-12	<.08						
SS 1*		0.93						
SS 2*		0.28						
SS 3*		0.27						
SS 4*		<.08						
SS 5*		<.08						

* Stream sediment samples from locations shown in Figure 8.

ORIGINAL (Red)

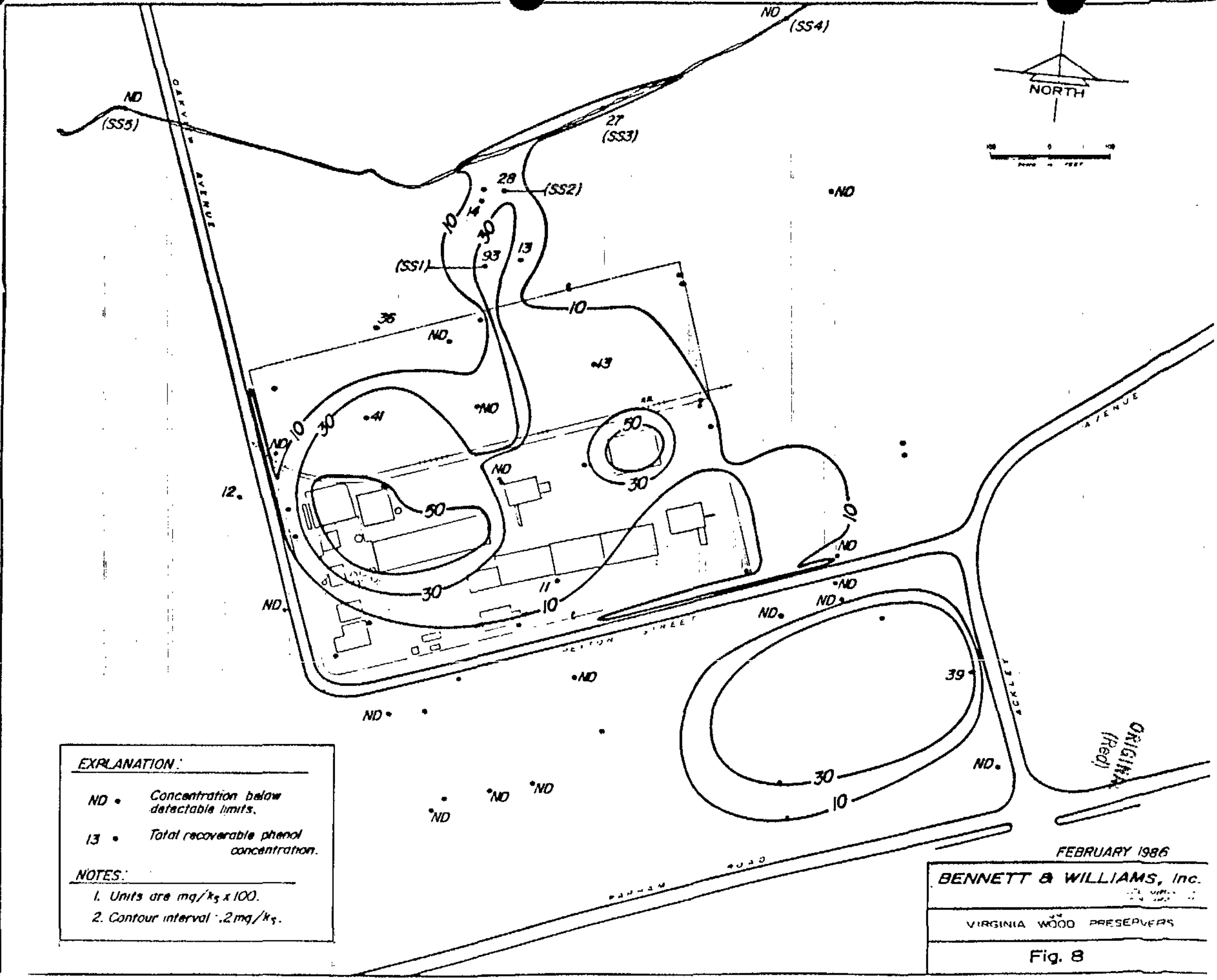


Fig. 8 - Total recoverable phenol concentrations in soil samples taken from depths

AR100339

and wells 3A and 10A, indicating non-detectable phenol concentrations, were not honored because of the likelihood of surface contamination in these areas. In addition, data from boring MS and well 14 were not honored. The sample taken from boring MS was rich in decomposed roots and leaves, and probably does not represent contamination from the site. Boring MS and well 14 are isolated from surface runoff from the site, and a likely path for contaminant migration is not apparent. Either of these samples may indicate surface application of phenolic compounds, however, and it is recommended that the samples be further analyzed in the future.

Figure 9 shows locations where run-off samples have been collected during a previous investigation. Analytical results are shown in Table 7. Potential problems with the analytical data will be discussed later. Pentachlorophenol, and creosote parameters, were detected in samples four and five, in the drainage area north of the site, samples two and six, in the ditch along Peyton Street, in sample three in a ditch routing surface water off-site into the area of standing water east of the site, and in sample one, in a ditch along Oakview Avenue.

The source of phenol in samples collected below 2.0 ft may represent contamination from several sources, including contaminated ground water, non-aqueous phase liquids, or infiltration of contaminated run-off. Plate 7 shows the probable depth of soil contamination at the site, and is based on field observations as well as total recoverable

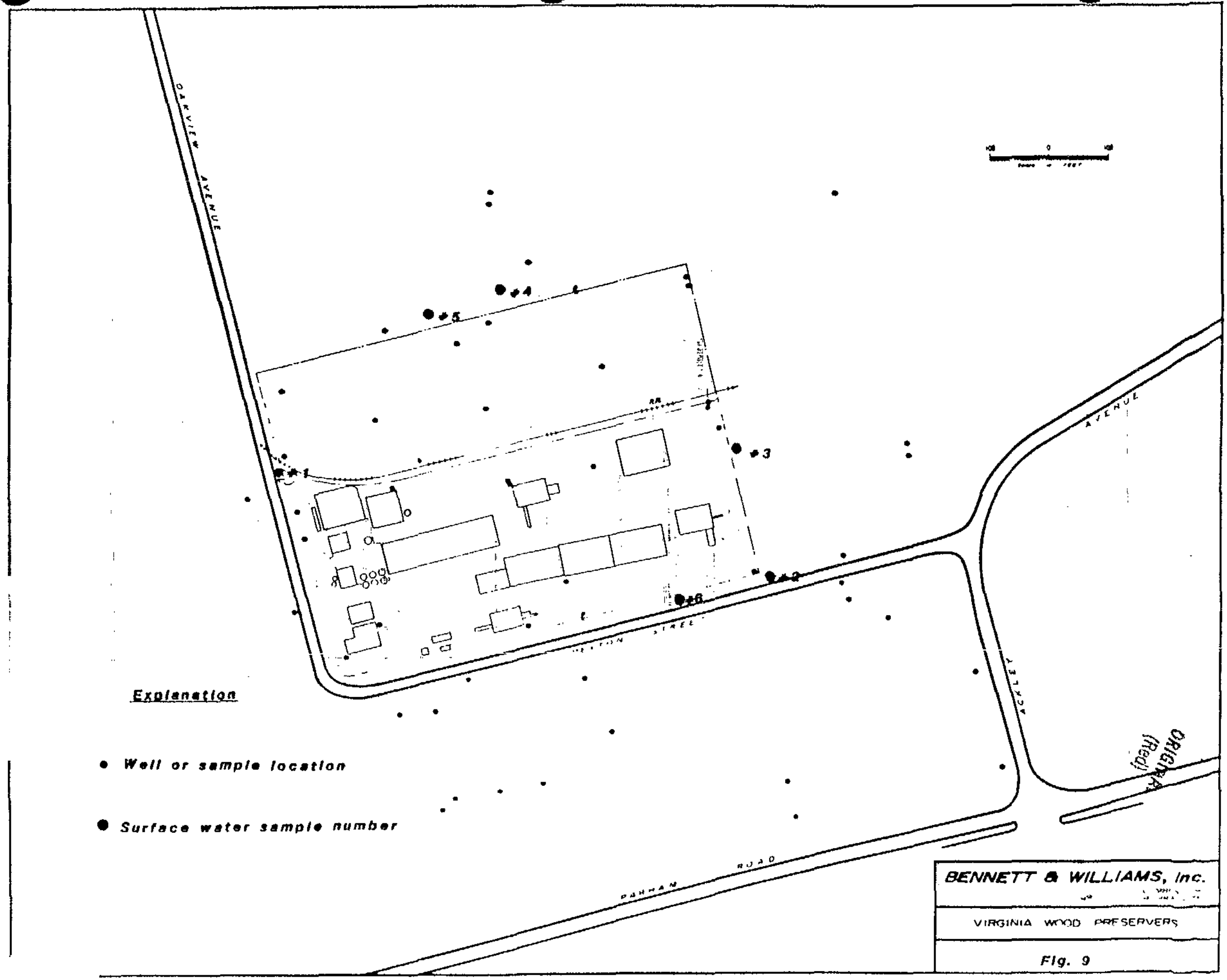

OAKVIEW AVENUE
AVENUE
ACKLEY
PARHAM ROAD
STREET
RR
#1
#2
#3
#4
#5
#6
ORIGINAL (Red)
Explanation
Well or sample location
Surface water sample number
BENNETT & WILLIAMS, Inc.
VIRGINIA WOOD PRESERVERS
Fig. 9

Table 7 – Laboratory analyses of surface run-off samples. Location of samples is shown in Figure 9.

Sample No.	Pentachlorophenol ug/l	Creosote ug/l	Copper mg/l	Chromium mg/l	Arsenic mg/l
1	14	28	0.06	<0.05	0.20
2	84	<2	0.26	0.08	0.52
3	44	1686	1.59	2.97	3.81
4	54	550	0.45	3.61	1.89
5	38	1408	0.33	0.10	0.69

phenol analyses of soil samples. The one foot contour represents contamination by infiltration of surface run-off. The seven foot contour location is based on the presence of contaminated soil samples from borings CS and GS, at depths of 5.8 to 6.2 ft, and 6.5 to 6.8 ft, respectively, and the location of the covered holding lagoon and blow-down sump, which are probable sources of the contaminant in the deeper sediments.

Aqueous Phase Contaminants

Analyses of ground-water samples have indicated that components of creoste and pentachlorophenol are present in wells 1, 2, 3, 4, 5, 6, 7, 8, 9, 10A, 11A, 13, D1, and D2. Available chemical analyses of ground-water samples are shown in Tables 8 and 9.

Total phenols, measured in water samples collected in November, 1985, indicate detectable concentrations (greater than 6.0 ug/l) in wells 1, 3A, 4, 9, 10A, and 11A (Table 8). As mentioned previously, this parameter must be used cautiously as a contaminant indicator, because of the presence of naturally-occurring phenols resulting from decomposition of natural materials. The data indicates that the shallow perched water table contains as much as 1.3 mg/l total phenols in the center of the site (well 3A), and 0.11 mg/l at the eastern boundary of the site (well 10A). The samples from adjacent wells (wells 3 and 10), screened in the weathered granite, showed non-detectable concentrations of total phenol. This supports the theory that non-aqueous

Table 8a - Laboratory water quality data from monitoring wells. TKN refers to total Kjeldahl nitrogen, COD refers to chemical oxygen demand, TOC refers to total organic carbon, TDS refers to total dissolved solids, TRP refers to total recoverable phenols, and MBAS refers to methylene blue active substances. Samples were collected in November, and December, 1985.

Well	Total Alkalinity	TKN	Nitrate	Sulfate	TDS	Chloride	MBAS	Ca	Mg	Fe	Na	K	Carbonate Alkalinity	Nitrite
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
GMW1	<1	2.25		57	222	20		7.6			22		0	
GMW2	11.9	0.05	0.93	<5.0	38	5.1	0.07	0.9	1.4	0.9	5.9	1.5	0	
GMW2A	5.5	0.24	<.02	<5.0	80	5.1	<0.05	0.9	1.4	23	5.6	1.5	0	
GMW3	35.9	0.14		<5.0	198	3.8	0.1	3			11		0	
GMW3A	9.2	0.23		<5.0	70	15		1.7			11		0	
GMW4	49	0.05	<0.02	48	1364	40	<0.05	4.9	3.6	15		3	0	
GMW5	18.5	0.42	0.19	<5.0	68	2.8		1.4			6.7		0	<.02
GMW6	35.9	0.48	0.29	<5.0	128	4.53	0.05	2.6	1.9	4.7	14	2.6	0	<.01
GMW7	41	0.45	0.12	<5.0	174	3.53		2.8	0.8	0.5	15	1.4	0	<.01
GMW8	<1	1.94	4.8	610	1928	535		12	1.1	61	532	3.8	0	
GMW9	23.6	0.76	0.17	8.4	876	28.9	<0.05	5.3	<20	13	25	0.9	0	<.01
GMW9A	<1	0.42	0.13	22	576	18		7.6			19		0	
GMW10	44.1	0.26	0.87	32	786	6.3	<.05	5.9			42		0	0.03
GMW10A	2.1	0.83	0.05	12	116	11	<.05	3.6			9.1		0	<.02
GMW11	8.3	0.17	0.69	170	168	834	0.1	2.8		156	593	12	0	
GMW11A	69.2	0.11	3.8	340	1434	29		9.4	5	3.8	335	4.7	0	
GMW12	4.1	0.2	1.3	<5.0	30	1.9	<.05	<.2	0.6	<.5	2.7	1.9	0	<.01
GMW13	9.2	0.39	0.2	6.1	86	19		1.3	0.3	2.1	16	2.3	0	<.01
GMW14	57.7	0.32	2.2	67	3012	17	<.05	9.7	5.4	43	97	3.8	0	
D1	84.1	0.06	0.05	210	602	25	0.11	26	18	8.8	126	5.8		
D2			<.02	330	771			39	18	13	140	2.1		

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Table 8a continued

Well	Cu	Cr	As	TRP	COD	TOC
	mg/l	mg/l	mg/l	ug/l	mg/l	mg/l
GMW1	<.1	<.05		84	115	44.9
GMW2	<.10	<.05		<6.0	<20	<1.0
GMW2A	<.10	<.05		<6.0	<20	5.1
GMW3	<.1	<.05		<6.0		5.4
GMW3A	<.10	<.05		1,300		21.2
GMW4	<0.1	<0.05		6	20	3.9
GMW5	<.1	<.05		<6.0	<20	1.6
GMW6	<.1	<.05	<.01	<6.0	<20	8.1
GMW7	0.12	<.05	<.01	<6.0	21	6.3
GMW8	0.31	0.41	0.07	<6.0	29	8.6
GMW9	<.10	<0.5	<0.02	7.1	23	3.6
GMW9A	<.1	<.05		<6.0	<20	2.9
GMW10	<.1	<.05		<6.0	<20	9.3
GMW10A	<.1	0.07		110	125	73.1
GMW11	0.18	0.39		<6.0	100	39.1
GMW11A	<.1	0.05		15	75	35
GMW12	0.14	<.05	<.01	<6.0	<20	<1
GMW13	<.1	<.05	<.01	<6.0	<20	<1
GMW14	<.1	<.05	0.03	<6.0	<20	4.8
D1	<.1	<.05			20	3.8
D2		<.05			<20	

Original Reg.

Table 8b - Concentrations of chemical parameters measured in-situ within each monitoring well.

Well	Temperature Centigrade	pH S.U.	Conductivity µmhos/sq cm	Dissolved Oxygen mg/l
GMW1	25.90	6.69	4180	0.94
GMW2	17.30	6.18	410	5.07
GMW2A	16.70	5.46	330	4.41
GMW4	20.40	6.36	2520	0.28
GMW5	19.60	7.34	690	2.15
GMW6	14.50	6.51	750	1.13
GMW7	14.00	6.70	820	5.45
GMW8	14.00	5.60	2340	6.85
GMW9	15.50	5.35	1770	0.43
GMW9A	17.30	4.75	1800	1.85
GMW10	17.70	6.46	2820	0.26
GMW11	17.00	5.21	308	2.54
GMW11A	15.80	5.66	1100	6.50
GMW12	14.30	5.14	370	4.27
GMW13	15.10	5.25	1120	1.85
GMW14	18.80	6.50	4070	0.98

Table 9 - Available chemical analyses of pentachlorophenol and creosote in groundwater samples.

Well/Date	Pentachlorophenol	Creosote
	µg/l	µg/l
GMW1/4-1-85	30	65
GMW2/4-1-85	45	432
GMW3/4-1-85	25	282
GMW4/4-1-85	39	1142
GMW5/4-1-85	<2	98
GMW1/4-24-85	10	9
GMW2/4-24-85	3	<2
GMW3/4-24-85	27	8
GMW4/4-24-85	104	204
GMW5/4-24-85	64	24
D1/4-24-85	<2	<2
D2/4-24/85	349	2
Blank1/11-85	14	10
Blank2/11-85	20	9
GMW6/11-85	44	<10
GMW7/11-85	154	42
GMW8/11-85	65	11
GMW13/11-85	55	12

phase liquids, present in the shallow perched water table, are the main source of contaminant at present, and that the hardpan, or friable clayey sand layer, restricts vertical movement of ground water. Detectable concentrations of total phenol were found in wells screened within the weathered granite in the northwest and southeast corners of the site, and to the east of the site (wells 1, 4, and 9, respectively). Data from wells 1 and 4 may be affected by well construction methods and materials. Each of these wells, however, is located near areas where the hardpan or friable clayey sand may be penetrated by excavation (well 4), or poorly developed (wells 1 and 9), and it is possible that concentrations represent contamination of ground water by phenolic compounds.

Figure 10 shows a contour map of total phenol concentrations in the ground water. Based on available data, concentrations of phenols in the shallow perched water table and weathered granite aquifers both were combined on the figure. Nevertheless, the map does show the general distribution of phenols across the site.

Copper, chromium, and aresenic concentrations, possibly indicative of contamination, were detected in wells 8 and 11 (Table 8). Copper was detected in wells 7 and 12. Low concentrations of chromium were detected in wells 10A and 11A, and a low concentration of arsenic was detected in well 14. To evaluate the effect of the CCA formulation presently used at the site on the ground water, it will be necessary to determine background values of copper, chromium, and

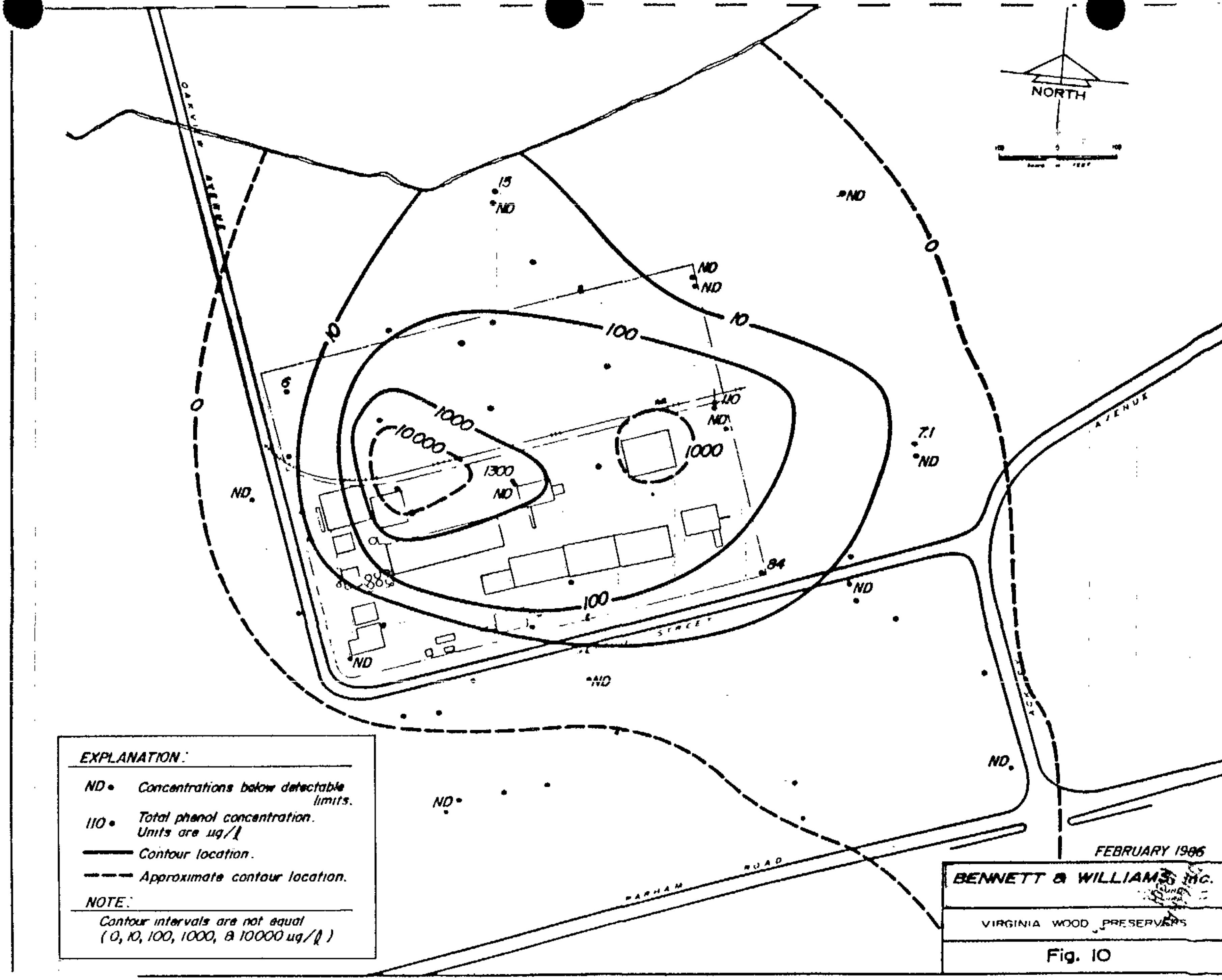

Fig. 10 – Total phenol concentrations, and probable extent of contamination, in groundwater at the site.

arsenic, using standard statistical methods. *In addition,* the retention capacity of the clay minerals at the site for copper, chromium, arsenic, and zinc should be evaluated, so that future migration of these ions in the ground-water system can be predicted.

Polynuclear aromatic hydrocarbon and phenolic compounds were not analyzed during the course of this investigation because of instrumental failure at the chemical laboratory. Creosote and pentachlorophenol concentrations determined from samples collected during previous investigations, shown in Table 9, are suspect because of questionable well construction and sample collection. The fact that total phenol concentrations were non-detectable (less than 6.7 ppb) in wells 2, 3, 5, 6, 7, 8, and 13, and that pentachlorophenol concentrations, which should be reflected in the total phenol analysis, were detected in these wells at concentrations varying from 25 to 154 ppb, indicates that either the analytical or sampling methods used to evaluate pentachlorophenol was not accurate, or contaminants introduced during the drilling process have since dissipated. The latter explanation is probably not likely, as the samples analyzed for pentachlorophenol and total phenol in wells 6, 7, and 8 were collected during the same sampling routine. To further complicate the analysis of data, bailer blanks collected during the November, 1985 sampling routine indicated contamination by both pentachlorophenol and creosote. Bailer blank number two was collected on a new teflon bailer prior to sampling. This indicates that the analytical techniques probably overestimate pentachlorophenol and creosote concentrations.

Despite problems with the data available, it is evident from field observations and total phenol concentrations that aqueous pentachlorophenol and creosote compounds are present in the ground-water system at the site. Product odor has been detected in wells 1, 3, 3A, 10A, and D2. The location of the zero contour interval shown on Figure 10 represents the approximate limits of potential ground-water contamination. The location of this line is based on field observations, hydrogeological and geological considerations, and the total phenol concentrations listed in Table 3.

Previous investigations of creosote and pentachlorophenol contaminated ground water have indicated that these contaminants are naturally degraded by microbial ecosystems in the ground-water environment, and are adsorbed by clay minerals. On one reported project, the farthest extent of contamination of creosote and pentachlorophenol compounds in a highly permeable aquifer was 1100 ft. Other similar investigations have identified maximum extents of migration of 1410, 570, and 400 ft (Barker and Patrick, 1985; Bedient and others, 1984; Ehrlich and others, 1982; Troutman and others, 1984). In each of these cases, research indicated that the migration of creosote and pentachlorophenol compounds was influenced by microbial degradation, adsorption by clays, and low solubilities of non-aqueous phase liquids.

CONTAMINANT FLOW PATHS AND AREAS INFLUENCED

ORIGINAL (Red)

Surface run-off of contaminated water flows into drainage areas around the Virginia Wood Preserving Corporation site. Several areas are affected, including the drainage area north of the site that drains directly into North Run Creek, the areas of standing water to the east and southeast of the site, and the runoff ditches along Oakview Avenue and Peyton Street. Contaminated surface run-off that enters the areas of standing water, shown on Plate 2, either degrade naturally, adsorb onto clay mineral surfaces, or infiltrate into the shallow perched water table and the weathered granite aquifer.

Non-aqueous phase liquids in the shallow perched water table aquifer appear to be contained on-site. The areal extent of these liquids is shown on Figure 7. Migration of the non-aqueous phase liquids has been retarded, and possibly halted, by the retention capacity of the soils. The amount of contaminant that exceeds residual saturations appears to be restricted at this time to the areas shown on Figure 7. The free-flow of non-aqueous phase liquids is not likely beyond these areas.

Aqueous phase contaminants in the shallow perched water table flow north toward North Run Creek. In the areas of mounding ground water, around the standing water east and southeast of the site, flow directions diverge to the east, west, and south. Flow to the south, induced by mounding of ground water around the area of standing water southeast of the site, is of particular concern. Contaminated surface water, routed under Peyton Street through the culvert shown on Plate 2, enters the shallow perched water table in the area of standing water southeast of the site. This means that aqueous contaminants may migrate southward across Parham Road.

ORIGINAL (Red)

Aqueous phase contaminants in the weathered granite aquifer migrate to the north toward North Run Creek. Flow to the south, across Parham Road, is possible in the same area where flow to the south occurs in the shallow perched water table.

Areas that are potentially affected are shown within the approximate zero contour in Figure 10. Ground-water monitoring wells are located over much of this area. To accurately delimit the area of contaminated ground water, however, additional monitoring wells, and monitoring well nests, are required. Recommended locations are shown in Plate 8.

Two of the recommended monitoring well nests are located south of Parham Road. If aqueous contaminants are detected in these wells, then further monitoring in this area will be required. Two additional monitoring wells are recommended just north of Parham Road; the east-most location will provide data on the potential flow path crossing Parham Road, and the western location will allow the extent of contaminated ground water in this area to be delineated.

Additional monitoring wells locations are also recommended north of the site, on both sides of North Run Creek. Data from these wells will allow the areal extent of contamination to be determined, and will confirm groundwater flow into North Run Creek from the north.

ORIGINAL (Red)

Contamination of soil and ground water at the Virginia Wood Preserving Corporation site warrants the design and operation of a contaminant recovery system. Although many remedial options are possible, several basic elements are essential for a successful clean-up of this site. These elements are:

1. Excavation and disposal of contaminated soils; or excavation of highly contaminated soils, followed by treatment of the remaining soils;
2. Hydraulic isolation of the site subsurface, through pumping wells in the weathered granite aquifer, and a perimeter french drain in the shallow perched water table, to prevent the migration of ground water from the site, followed by appropriate treatment of recovered water. For contaminated ground water outside the site perimeter, natural or enhanced degradation, if feasible, or recovery and treatment;
3. Surface water isolation, to prevent the migration of contaminated run-off from the site, and minimize infiltration into soils;
4. Continued monitoring of water quality.

Plate 8 shows various elements of the recommended remedial action plan referred to in the following discussion.

Excavation of Contaminated Soils

Based on the areal extent and depth of contaminated soils, as illustrated in Plate 7, as much as 500,000 cubic feet of contaminated sediment may exist on and around the site. The soils in the vicinity of the concrete holding pond, and the covered holding lagoon, have been contaminated to concentrations that may inhibit natural or enhanced degradation, and it is therefore considered more cost-effective to excavate and dispose of this material rather than attempting to recover the product. These areas are designated as areas requiring excavation in Plate 8, and the volume of these sediments is estimated to be between 100,000 and 180,000 cubic feet. Disposal can be acheived by removal to an approved disposal site, or on-site incineration.

ORIGINAL (Red)

The areal extent, and estimated depths, of the remaining contaminated soils are shown in Plate 7. Several methods of handling these remaining contaminated sediments should be considered, including: (1) excavation and disposal, either by removal to an approved disposal site, or on-site incineration; (2) excavation and disposal of soil with non-aqueous phase liquids, followed by on-site treatment, either by isolation or managed land application, of the remaining soil; or (3) recovery of free-floating product from shallow recovery wells, or lateral french drains, followed by in-situ enhanced biodegradation. Options two and three will require a feasibility study to determine the reliability of the methods.

Option one, excavation and disposal of the remaining contaminated soils, would be the most costly option of the three. It does have significant advantages, however. Excavation would eliminate the source of ground-water contamination quickly and effectively. Annual operational costs for this element of the remedial plan, associated with options two and three, would be eliminated for this element of the remedial plan.

Option two involves excavation and disposal of soils which contain free-floating non-aqueous liquids, and which therefore may not be susceptible to natural or enhanced degradation, followed by on-site treatment of the remainder of the soil. Basically, this option would involve careful examination and analysis of the excavated soil, and separation of soil to be disposed of based on criteria yet to be determined. The remainder of the soil would be treated on-site, either through isolation, land application, or enhanced biodegradation.

Isolation of soils with trace levels of contaminant may be viable, provided that hydraulic isolation is acheived, no free-floating non-aqueous phase liquids are present, and natural or enhanced degradation of the remaining contaminants occurs. Land application involves careful spreading of contaminated soil over a large, hydraulically isolated area, and naturally enhancing degradation of the contaminants through exposure to sunlight and the atmosphere, and breakdown and adsorption by plants and natural bacteria.

Option three is based on the assumption, yet to be confirmed, that the balance of the contaminated soil not excavated can be treated on-site by some form of enhanced biodegradation. This option also assumes that a majority of the free-floating non-aqueous phase liquids can be recovered, through shallow recovery wells, or lateral french drains. Potential problems that may be encountered with such recovery systems have been discussed previously. Although this would be the most cost-effective option if the site were to remain in operation, the suitability of this system must first be demonstrated by a feasibility study.

Hydraulic Isolation of the Site

To prevent migration of contaminanted ground water off-site, the site must be hydraulically isolated. Based on the results of the ground-water flow model, approximately 135 gpd flows through the site. Pumping collection systems, however, will increase the flow of ground water into the site. Therefore, the amount of ground water which must be removed from the aquifers, and treated, will necessarily be greater than 135 gpd. Discharge from pumping wells and the shallow french drain should be routed to a holding lagoon for temporary storage, and treated.

To evaluate the most efficient and cost effective pumping rate, and pumping well orientation, it is recommended that several alternative recovery scenarios be incorporated into the ground-water model. This study, in conjunction with a pumping test of the weathered granite aquifer, will allow proper design of the pumping wells and should serve as part of a feasibility study for this portion of the remedial action plan.

ORIGINAL (Red)

Based on the estimated extent of contamination, shown in Figure 10, contaminated ground water may exist over an area as large as 30 acres. It will be difficult to attempt to recover contaminated ground water over this area with on-site collection systems, because of the relatively low transmissivities in the weathered granite aquifer. Therefore, to determine the required remedial steps, an investigation should be undertaken that further evaluates the rate of migration, and the extent of natural degradation of the organic compounds.

Previous investigations have shown that natural degradation of phenolics and polynuclear aromatic hydrocarbons typically occurs within approximately 2000 feet of the source of contaminant. If the source of contaminant at the Virginia Wood Preserving Corporation site is effectively removed, then it may be possible to rely on degradation by the microbiological ecosystem in the ground-water system, and adsorption by clay minerals. In fact, because of relatively slow migration rates of organic compounds, it may not be possible to recover the contaminants with a large scale pumping system before they degrade naturally. If this option proved not to be feasible, then enhanced bioreclamation should be considered.

To control the influx of shallow ground-water during excavation, avoid release of contaminants during excavation, and recover any remaining non-aqueous phase liquids, a perimeter french drain should be installed around the area where free floating non-aqueous phase liquids have been detected (Figure 7). The french drain would extend to a depth ranging from three to eight feet, and be excavated into, but not penetrate, the friable sandy clay at the base of the regressive fluvial sediments. The total length of the required french drain will be approximately 2200 ft, and would average a depth of five feet. The french drain will be located around the area designated as the controlled area, shown in Plate 8. Discharge from the french drain should be routed to a holding lagoon for temporary storage, and treated.

ORIGINAL (Red)

Surface Run-off Management Plan

Contaminated run-off presently flows off-site to the north, toward North Run Creek, and into the areas of standing water shown on Plate 2. In the future, to prevent contaminated run-off from leaving the site, surface water must be isolated on-site. The basic elements required to isolate surface waters on-site are:

1. Regrading of the site, so that surface water flows to perimeter ditches;
2. Installation of ditches, or culverts to intercept and direct run-off;
3. Installation of berms, surrounding the ditches or culverts, to prevent overflow;
4. Construction of a surface water retention area, to collect and store run-off.

Regrading of the site should place the maximum elevation at the center of the site, and direct run-off towards ditches or culverts at the perimeter of the site. This arrangement will prevent ponding of water, and increased infiltration, in the center of the site. Culverts should be used, in lieu of excavated ditches, if either option two or three of the excavation program is chosen, or if the site remains operational. Design of the culverts and berms should be based on the maximum anticipated run-off.

To reduce infiltration into soils, a low permeability cap should be placed over the regraded material. This may be either a clay cap, or an artificial cap of material such as high density polyethylene (HDPE). The installation of either cap will serve to reduce the size of the treatment volume, however, the installation of an HDPE cap may be impractical if the site is to remain operational. Over the low permeability cap, a layer of protective soil should be emplaced. If the site is to be closed, then runoff and infiltration can be further reduced by a vegetative cover on the protective soil layer.

Continued Monitoring of Water Quality

To continue monitoring the extent of contamination, and to evaluate effects of remedial action, a routine of sampling and analysis of ground water should be initiated. Monitoring wells 8 through 14, as well as the recommended wells shown on Plate 8, should be included in the monitoring plan. Sampling and laboratory analysis should be performed quarterly. Quality control should be developed and enforced so that consistent and reproducible results are obtained. After reliable sampling and analytical results have been acheived, and seasonal variations in chemical parameters are understood, sampling and analytical results should be repeated as needed, probably bi-annualy.

Sampling methods for evaluating trace organic compounds, and particularly volatile organics, require the attention of sampling personnel familiar with proper well development and sampling techniques. Sophisticated analytical techniques, with detection limits in the ug/l to low mg/l range, are of no advantage with improperly collected samples. Sampling techniques that should be considered include the tube and cartridge method, the use of a low capacity bladder pump, and dedicated bladder pumps.

Chemical parameters that should be analyzed are shown in Table 10. These parameters are based on results of previous investigations, and similar studies, and should be modified as more is learned about the nature of the contaminants present.

ORIGINAL (Red)

Table 10 — Recommended chemical parameters for monitoring program.

INORGANIC COMPOUNDS

Total alkalinity
Total Kjedahl Nitrogen
Nitrate Nitrogen
Chemical Oxygen Demand
Total Organic Cabon
Specific Conductance
pH
Dissolved Oxygen
Arsenic
Aluminum
Calcium
Chromium
Barium
Chloride
Copper
Iron
Manganese
Nickel
Potassium
Sodium
Zinc

ORGANIC COMPOUNDS

Polynuclear Aromatic Hydrocarbons and Related Coumpounds:

Total PAH's
Napthalene
2-Methylnapthalene
1-Methylnapthalene
2,3 Dimethylnapthalene
Acenapthalene
Acenapthene
Anthracene
Benzo(A)anthracene
Fluorene
Phenanthrene
Carbazole
Fluoranthene
Benzo(k)fluoranthene
Pyrene
Benzo(A)Pyrene
Indeno (1,2,3-cd)pyrene
Benzo (g,h,i)Perylene
Chrysene
Benzo(A)pyrene
Dibenzofuran

Phenolic Compounds:

Total Phenols
2-methylphenol
3-methylphenol
4-methylphenol
2,5 and 2,4-dimethylphenol
3,5-dimethylphenol
Pentachlorophenol

Volatile Organics:

Benzene
Ethylbenzene
Tolulene
o-xylene
styrene

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(Red)

Discussion

Within the framework of the remedial methods discussed above, there are a number of decisions which must be made. The principal factors to be considered in making these choices are technical feasibility, efficiency, manageability, and incurred liability. The ideal solution favorably combines all the above factors, however, in reality there will be a trade off. For example, a decision must be made regarding whether contaminated soils are to be removed and landfilled at an approved site, incinerated at an approved site, or incinerated on-site. Although it appears to be cost-effective to landfill the contaminated soil, the "joint and several liability" provisions of present law may incur long-term liabilities. Incineration at an approved site may prove to be substantially more expensive than the cost of landfilling, but presumably once it is incinerated, long-term liability is minimized. On-site incineration is a relatively new method of treatment, and although the method may prove to be technically feasible, the cost effectiveness, and liabilities incurred, remain uncertain.

Another decision which must be made concerns the continued operation of the plant. If it is decided to provide on-site treatment of the contaminated soil or water, and continue operation of the plant, then increased maintenance of the cap material and other elements of the remedial system will probably be required. Quantities of water, from surface run-off and ground-water, will probably be increased without a well developed vegetative cover serving to reduce infiltration.

ORIGINAL (Red)

Unproven technologies, such as controlled natural degradation, on-site incineration, and land spreading, as well as technologies that have not been thoroughly tested with the contaminants particular to this site, such as hydraulic recovery of non-aqueous phase liquids, and enhanced biodegradation, will require thorough investigation at considerable expense. If these options are proven to be feasible, however, the efficieny and cost effectiveness of the remedial operation may be greatly enhanced. Therefore, perhaps the most basic decision to be made is whether to use well established remedial options, which may be less efficient and less cost effective; or consider remedial technologies that will incur greater investigative costs, and may potentially increase liability and accountability, but may significantly increase efficiency and cost effectiveness. These basic approaches, as they apply to this site, are outlined below:

Alternate A:

1. Hydraulically isolate the site, both surface and subsurface. Induce flow of contaminated ground water toward the site for treatment.
2. Excavate and remove all soils contaminated in excess of pre-set criteria, with:
    a) landfill disposal option
    b) incineration disposal option

c) on-site incineration disposal option

ORIGINAL (Red)

3. Cap with HDPE, or equivalent cap, establish vegetative cover, and close site.

4. Obtain RCRA permit. Collect and treat ground water, as needed. Monitor and operate system until acceptable standard attained, or permission to discharge to public sewers recieved.

Alternate B:

1. Hydraulically isolate the site, both surface and subsurface. Investigate technical feasibility of natural or enhanced degradation of contaminants.

2. Excavate and remove soils requiring excavation, shown on Plate 8.

3. Investigate remedial options for on-site treatment of remaining contaminated soils, and remove those soils determined to be too contaminated for on-site treatment, with;

   a) landfill disposal option

   b) incineration disposal option

   c) on-site incineration disposal option

4. Obtain RCRA permit. Collect and treat ground water, as needed to hydraulically isolate site. Investigate remedial options for natural or enhanced biodegredation of contaminated ground water. Monitor and operate system until acceptable standard attained, or permission to discharge to public sewers is recieved. Operational options:

   a) cap and close site as treatment progresses.

b) continue plant operation as treatment progresses.

ORIGINAL (Red

The principal difference between the two alternatives is that Alternate A requires a closed site, and Alternate B allows the option of an open site. Both of the alternatives will require additional hydrogeological and chemical data, design of surface and subsurface recovery systems, and feasibility studies of the recovery and treatment methods used. Alternate A can be viewed as a combination of established and conservative remedial options, with provisions to minimize liability. The advantages of alternate A must be weighed against the decrease in cost effectiveness, and potential decrease in efficiency and timeliness of clean-up.

CONCLUSIONS

1. Wood treatment operations at the Virginia Wood Preserving Corporation site began in June, 1956. Contamination of soil and ground water has resulted from seepage of process liquids in the treatment area, and through unlined holding areas. Contaminants that have been identified are compounds associated with creosote, pentachlorophenol, and CCA. Contamination by other formulations used at the site, such as CZA, xylene, and No. 2 fuel oil can not be evaluated until appropriate chemical parameters are analyzed in soil and ground-water samples.

Several elements of the wood treatment process that contributed to contamination of soil and ground water have been removed. Other elements responsible for contamination are not currently in use. Sources of ground-water contamination at present consist of immiscible liquids present in soils on-site, the covered holding lagoon, and occasional seepage of CCA from the treatment process.

2. Bedrock beneath the site is Upper Paleozoic Petersburg Granite. This unit is relatively impervious to infiltration of surface water, and ground water from shallow water bearing units, except through fractures and severely jointed areas. Joints in the unit are typically horizontal, or vertical, and trend in a northerly or easterly direction. A fracture trace analysis revealed no discernable surface expression of fractures trending through the site.

ORIGINAL (Red)

Well D2, a deep water supply well on-site, may be contaminated through cross-connection with shallow water bearing units. Potential contamination of the granite aquifer, by cross-connections, or through hydraulic connection through fractures, can not be evalutated until additional monitoring wells, screened within the granite aquifer, are installed.

3. Ground-water flow within the weathered granite aquifer trends to the north and northeast across the site. Aquifer boundaries occur to the south, trending along Parham Road, and to the north, along North Run Creek. A shallow perched water table occurs within the regressive fluvial sediments that unconformably overlay the weathered granite. The shallow water table is perched by a hardpan, or friable clayey sand layer, that has developed at the base of the regressive sediments. Aquifer boundaries within the shallow perched water table are consistent with boundaries in the weathered granite aquifer, except in areas of standing surface water. Ground-water mounding in these areas causes local deviations in flow within the shallow perched water table.

4. The ground-water flow model, calibrated with geologic and hydrogeologic parameters estimated during this investigation, indicates that approximately 135 gpd, was flowing through the site in late January, 1985. Transmissivity of the weathered granite aquifer is estimated at 9.2 gpd/ft, plus or minus 4.5 gpd/ft. The hydraulic conductivity of the regressive fluvial sediments is

estimated to vary from 0.2 to 2.0 gpd/ft , and averages 1.3 gpd/ft .

ORIGINAL (Red)

5. Surface run-off of process formulations and contaminated water has resulted in soil contamination over a large portion of the site, and in several areas around the site. A culvert under Peyton Street appears to be responsible for transport of contaminated water into the area of standing water southeast of the site. Contaminated waters, infiltrating into the shallow water bearing units in this area, may flow to the south, across Parham Road.

6. Ground-water monitoring wells 1, 2, 3, 4, and 5, installed during a previous investigation, are constructed in such a way that cross-connection, and adsorption of organic compounds on the well materials, may be occurring. These wells, and deep wells D1 and D2, may be cross-connecting water bearing units on-site.

7. Organic compounds have been observed in three liquid phases at the site; a light immiscible liquid, a dense immiscible liquid, and an aqueous liquid. The non-aqueous phase liquids are probably derivatives of creosote and pentachlorophenol, and the aqueous phase contaminants result from the slow dissolution of non-aqueous phase liquids, and infiltration of contaminated surface water.

The non-aqueous phase liquids appear to be relatively immobile, and confined to the site. The light immiscible phase is present within the capillary zone and upper portion of the water table zone of the shallow perched water table. Free-flowing light immiscible liquids have been observed in two borings and one well on-site. The dense immiscible phase is within the lower portions of the shallow perched water table, and probably can not migrate through the hardpan, or friable clayey sand layer, because of the large capillary forces encountered.

Aqueous phase contaminants within the shallow water bearing units are largely derived from dissolution of the immiscible liquids. Therefore, contaminant concentrations are controlled by the solubility of the immiscible liquids. Aqueous phase contaminants may be present over an area of approximately 30 acres. Migration of these contaminants appears to be controlled by aquifer boundaries, and is probably influenced by natural degradation.

ORIGINAL (Red)

1. The ground-water monitoring wells installed during a previous investigation of this site are possibly cross-connecting the shallow perched water table and the weathered granite aquifer. Materials used to construct these wells are not appropriate for monitoring organic compounds. Therefore, it is recommended that wells 1, 2, 3, 4, and 5 be removed, properly plugged, and replaced. Wells 6 and 7 should be sampled, and if organic compounds are detected, these wells should also be removed, properly plugged, and replaced.

2. Also, the deep water wells on-site may be cross-connecting the shallow water bearing units and the granite aquifer, thereby providing a source of contamination of the granite aquifer. Three deep monitoring wells within the granite aquifer are recommended so that, ground-water flow directions and gradients can be determined, and potential contamination of this aquifer can be evaluated. Monitoring of static water level, and test pumping, of these wells will be required to determine any hydraulic connections between the granite aquifer and the weathered granite aquifer. Locations for these wells are shown in Plate 8.

3. Additional monitoring wells, and monitoring well nests, are needed within the shallow water bearing units, to further delineate the extent of contamination and evaluate ground-water flow and potential contaminant migration to the

south of Parham Road. Locations for these recommended monitoring wells are shown in Plate 8.

4. Quarterly sampling and analysis should be performed on all monitoring wells until sampling and analytical techniques that are reliable and reproducible are developed, and until seasonal variations in water quality are understood. One upgradient, and two downgradient sampling locations should be established on North Run Creek, and included in the sampling and analysis program. Sampling and analytical methods should address the potential problems inherent in evaluating quantities of trace and volatile organic compounds. Chemical parameters which should be evaluated are shown in Table 10. As the data base is expanded, this list should be modified accordingly.

5. Contamination of soil and ground water at the Virginia Wood Preserving Corporation site warrants remedial action. Options that will clean-up the existing contamination, and prevent contamination in the future are discussed. The remedial methods selected will depend on a number of factors, including technical feasibility, efficiency and timeliness, manageability, and incurred liability. However, the following essential elements of the remedial plan include: (1) the excavation and disposal of a minimum of 100,000 cubic feet of contaminated soil, as shown in Plate 8; (2) hydraulic isolation of the site, through pumping of the weathered granite aquifer, and emplacement of a french drain in the shallow perched water table zone, followed by treatment of recovered water; (3) installation of berms

and culverts around the site perimeter, and regrading of site, to control surface run-off; and (4) continued monitoring of water levels and quality, to monitor ground-water contamination, and evaluate the effectiveness of the remedial methods.

6. To design or operate any remedial plan, additional hydrogeological and chemical data must be collected, and interactions between the contaminants and the soil and ground-water environments must be more clearly defined.

In the discussion of remedial methods, several options for each of the basic elments of the required remedial plan are outlined. In an effort to utilize the most efficient and cost-effective methods possible at the site, we recommend that the following investigations be undertaken:

A. Physical and chemical characteristics of the non-aqueous phase-liquids present, and the interaction of these liquids with the soils present, should be determined. This will allow the feasibility of a shallow recovery system for these contaminants to be evaluated. Excavation criteria, and the feasibility of in-situ treatment, based on the concentrations of contaminant inhibiting natural or enhanced degredation, should be determined.

B. The effect of the microbiological ecosystem in the ground-water system on contaminants should be investigated, so that natural degradation rates can be estimated. Based on this investigation, the need for biodegredation, or a large scale recovery system for aqueous contaminants within the weathered granite aquifer can be evaluated.

C. A pumping well, and several observation wells, should be installed at the site, and pumping tests should be performed, so that pumping wells for hydraulic control of the weathered granite aquifer can be designed. The ground-water flow model, developed during this investigation, should be used to evaluate various locations and spacings for the pumping wells. Based on the results of the ground-water flow model simulations, a configuration of pumping wells which minimizes the amount of water requiring treatment, and efficiently controls ground-water flow within the weathered granite aquifer, can be implemented. The ground-water flow model should also be used to evaluate the influence of excavation, and emplacement of the french drain, on the free-floating non-aqueous phase contaminants within the shallow perched water table.

Respectfully Submitted,
BENNETT & WILLIAMS, INC.

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REFERENCES

ORIGINAL (Red)

Barker, J.F. and G.C. Patrick, 1985, Natural Attenuation of Aromatic Hydrocarbons in a Shallow Sand Aquifer; in Proceeding of the Petroleum Hydrocarbons and Organic Chemicals in Ground Water - Prevention, Detection, and Restoration, p. 160-177.

Bedient, P.B., A.C. Rodgers, T.C. Bouvette, M. B. Tomson, and T.H. Wang, 1984, Ground-Water Quality at a Creosote Waste Site, Ground Water, v.22, no. 3, p. 318-328.

Brobst, R. B. and P.M. Buszha, 1986, The Effect of Three Drilling Fluids on Ground-Water Sample Chemistry, Ground Water Monitoring Review, v. 6, no. 1, p. 62-70.

Clay, J. W., 1975, Soil Survey of Henrico County, Virginia, USDA Soil Conservation Service, 119 pp.

Ehrlich, G.G., D.F. Goerlitz, E.M. Godsy, and M.F. Hult, 1982, Degradation of Phenolic Contaminants in Ground Water by Anaerobic Bacteria: St. Louis Park, Minnesota, Ground Water, v. 20, no. 6, p. 703-710.

McDonald, M.G. and A.W. Harbaugh, 1984, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, USGS, Reston Va, 528 pp.

Troutman, D.E. and others, 1984, Phenolic Contamination in the Sand-and-Gravel Aquifer from a Surface Impoundment of Wood Treatment Wastes, Pensacola, Florida, USGS Water Res. Invest. Report 84-4230, 36 pp.

Wilson, J.L. and S.H. Conrad, 1984, Is Physical Displacement of Residual Hydrocarbons a Realistic Possibility in Aquifer Restoration?; in Proceedings of the NWWA/API Conference on Petroleum Hydro-carbons and Organic Chemicals in Ground Water - Prevention, Detection, and Restoration, p. 274-298.

ORIGINAL
(Red)

APPENDICES

ORIGINAL
(Red)

APPENDIX ONE

BORING LOGS OF SUBSURFACE MATERIALS

ORIGINAL (Red)

Table A - Symbols used in soil descriptions..

Fill	Friable clayey sand
Clay	Loosely cemented clayey sand
Sandy clay	Weathered granite
Silt	Silty clay and sand
Clayey sand	Granite

Boring descriptions from previous investigations of the site are presented in this section. Borings which have been renamed and shown on Plate 2, the site location map, are listed below.

Boring Designation on Logs	Boring Designation on Plate 2
B-1	P
B-2	Q
B-3	R
B-4	V
B-5	Y

During previous investigations, two borings, each called B-2, were installed. The name of the boring on Virginia Wood Preservers property is B-2 on Plate 2. The boring in Parham Forest is renamed as Boring Q on Plate 2.

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ORIGINAL
(Red)

BORING: GMW3A
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 9/10/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 209.1
CASING ELEVATION : 209.6

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	15"	20-12		0.0-1.3' Dark gray clay and sand, some silty, dry, very stiff. Faint product odor.			
	SS2	13"	3-4		1.3-3.4' Light brown-yellow sand and clay, some silt, medium stiff, damp, semi-plastic. Faint product odor.			
	SS3	16"	8-12					
5					3.4-6.6 Yellow-brown fine to coarse sand and clay, some silt, very stiff, friable, dry to damp. Product odor.	CL	26	25
	SH1	13"						
10								
15								
20								
25								
30								

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BORING: GMW2A
METHOD: 3.5" HOLLOW STEM AUGER
DATE: 10/8/85
PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SURFACE ELEVATION : 208.0 CASING ELEVATION : 209.0 SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
					NO SAMPLES WERE TAKEN. LOG IS EXTRAPOLATED FROM BORING GMW2.			
					0.0-2.5' Yellow brown red and gray clay and sand, some silt, medium stiff, damp.			
5					2.5-5.0' Gray and yellow-brown sand and clay, some silt, damp, very stiff.			
					5.0-7.3' Light gray fine to coarse sand and clay, some silt, friable, hard, damp.			
10								
15								
20								
25								
30								

AR100381

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ORIGINAL
(Red)

BORING: GMW3A
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 9/10/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 209.1
CASING ELEVATION : 209.6

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	15"	20-12		0.0-1.3' Dark gray clay and sand, some silty, dry, very stiff. Faint product odor.			
	SS2	13"	3-4		1.3-3.4' Light brown-yellow sand and clay, some silt, medium stiff, damp, semi-plastic. Faint product odor.			
	SS3	16"	8-12					
5					3.4-6.6 Yellow-brown fine to coarse sand and clay, some silt, very stiff, friable, dry to damp. Product odor.	CL	26	25
	SH1	13"						
10								
15								
20								
25								
30								

AR100382

ORIGINAL (Red)

BORING: GMW6
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 8/29/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 212.0'
CASING ELEVATION : 213.2'

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1		W.H.-2-2		0.0-0.6' Black clay loam, soft, roots, organics.			
	SS2		4-50-80		0.6-1.9' Gray clay and sand, some silt, soft, damp. No product odor.			
5	SS3		32-100					
	SS4		8-11-13		1.9-8.7' Light gray-white fient to coarse sand, some clay, with silt, dry to damp, friable, loosely cemented. No product odor.			
10	SS5		5-11-13					
					8.7-14.0' Light gray-brown fine to coarse sand, some clay and silt, trace gravel, wet, medium dense. No product odor.			
15	SS6		18-23		14.0-21.0' Light gray-white fine to coarse sand and clay, red-brown mottling, dense to very dense, wet. No product odor.			
	SS7		25-42					
20	SS8		13-75					
25								
30								

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ORIGINAL
(Red)

BORING: GMW7
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 8/30/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 210.0
CASING ELEVATION : 211.1

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1		W.H.-3-3		0.0-0.6' Dark brown-black clay loam, roots, organics, dry, soft. No product odor.			
	SS2		7-100X		0.6-1.9' Gray clay and sand, some silt, medium stiff, dry. No product odor.			
5	SS3		21-100		1.9-2.6' Gray sand and clay, some silt, medium stiff, dry. No product odor.			
	SS4		34-16-16		2.6-7.0' Light gray-white fine to coarse sand, some clay and silt, friable, hard, loosely cemented, dry to damp, red-brown mottling. No product odor.			
10	SS5		10-12-14					
					7.0-21.5' Light gray-white fine to coarse sand, some clay, little silt, trace gravel, very stiff, wet. No product odor.			
15	SS6		3-3					
20	SS7		4-8					
					Auger refusal on granite at 21.5'.			
25								
30								

BORING: GMW8　　DATE : 9/25/85　　PROJECT: VIRGINIA WOOD PRESERVERS

METHOD: 3.5" HOLLOW STEM AUGER　　LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.1
CASING ELEVATION : 208.2

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	17"	1-1-3		0.0-0.2' Dark brown clay loam, little silt, organics, wet.			
					0.2-1.5' Grey clay and sand, some silt, wet, soft. No product odor.			
	SS2	17"	4-9-15		1.5-5.5' Gray sand and clay, some silt, trace gravel, wet, red brown mottling, wet, stiff. No product odor.			
5	SS3	21"	11-17-28					
	SS4	18"	21-22		5.5-7.7' Dark gray fine to coarse sand and clay, some silt, trace gravel, light brown-red mottling dry to damp, friable, hard. No product odor.			
	SS5	18"	16-25		7.7-8.2' Yellow-brown clayey silt and sand, wet, no-plastic, soft. No product odor.			
10					8.2-12.0' Light gray-white fine to coarse sand and silty clay, red-brown mottling, wet, hard. No product odor.			
	SS6	18"	22-31-55		12.0-12.3' Gray clayey silt, wet, thin sand seams. No product odor.			
15					12.3-17.8' Light gray-white fine to coarse sand and silty clay, red-brown mottling, wet, hard. No product odor.			
	SS7	14"	28-55-100X		Auger refusal on granite at 17.8'.			
20								
25								
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AR100385

CONSULTING GEOLOGISTS

Original (Red)

BORING: GMW9
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 9/17/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.5
CASING ELEVATION : 208.4

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	13"	4-5-4		0.0-0.7' Dark brown clay loam, some silt, dry, roots, medium stiff. No product odor.			
	SS2	24"	5-5-9		0.7-3.5' Gray-brown clay and sand, stiff, dry, semi-plastic. No product odor.			
5	SS3	20"	12-84-100X		3.5-4.0' Light gray-brown fine to coarse sand and clay friable, very stiff, damp. No product odor.			
					4.0-6.0' Light gray-white sand and clay, some silt, dry to damp, hard, brown-red mottling, friable, loosely cemented. No product odor.			
10	SS4	12"	4-7-9		6.0-9.5' Light gray-brown fine to coarse sand and clay friable, very stiff, damp. No product odor.	CL	20	32
					9.5-14.5' Light gray-white sand and clay, some silt, dry to damp, hard, brown-red mottling, friable, loosely cemented. No product odor.			
	SS5	13"	4-7-11		14.5-17.0' Yellow-brown silty clay and sand soft, wet. No product odor.	ML	N/P	20
15					17.0-17.6' Light gray-white fine to coarse sand and silty clay, red-brown mottling, wet, medium dense. No product odor.			
	SH4	0"	12-100x		Auger refusal on granite at 17.6'.			
20								
25								
30								

AR100386

ORIGINAL

BORING: GMW9A DATE: 10/8/85 PROJECT: VIRGINIA WOOD PRESERVERS

METHOD: 3.5" HOLLOW STEM AUGER

LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.5

CASING ELEVATION : 208.6

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
					NO SAMPLES WERE TAKEN. LOG IS EXTRAPOLATED FROM BORING GMW9.			
					0.0-0.7' Dark brown clay loam, some silt, dry, roots, medium stiff. No product odor.			
					0.7-3.5' Gray-brown clay and sand, stiff, dry, semi-plastic. No product odor.			
5					3.5-4.0' Light gray-brown fine to coarse sand and clay friable, very stiff, damp. No product odor.			
					4.0-6.0' Light gray-white sand and clay, some silt, dry to damp, hard, brown-red mottling, friable, loosely cemented. No product odor.			
10					6.0-7.2' Light gray-brown fine to coarse sand and clay friable, very stiff, damp. No product odor.			
15								
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CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: GMW10
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 9/11/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION: 210.1
CASING ELEVATION: 210.4

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	12"	2-3-4		0.0-4.3' FILL: Red sandy clay, micaceous, dry			
	SS2	9"	6-9-8		4.3-5.3 Dark gray-black silty clay loam, organic rich, soft, roots, damp.			
5	SS3	23"	2-2-3		5.3-7.4 Gray-brown sand and clay, some silt, wet, non-plastic, medium stiff. Faint product odor.			
	SS4	16"	10-33 -50X		7.4-12.0 Light gray-white sand and clay, dry, loosely cemented, friable, hard. No product odor.	SC	9.9	24.6
10								
					12.0-12.5 Variegated green, red, and yellow fine to coarse sand with little clay, damp, medium dense. No product odor.			
	SS5	18"	6-7					
15	SS6	12"	6-7		12.5-16.6 Variegated red, brown, yellow fine to coarse sand with silty clay, trace fine gravel, wet, semi- plastic. No product odor.			
	SH2	7"				SC	17	33
	SS7	18"	34-50		16.6-17.2 Brown-yellow fine to medium sand with little clayey silt, loose, wet. No product odor.			
20								
	SS8	12"	61-90 -75		17.2-24.5 Brown clayey sand with some silt. Mottled intervals (3") of gray-white and red brown, very dense. wet. No product odor.			
	SS9	17"	30-37 -70					
25	SS10	5"	100X		Auger refusal on granite at 24.5'.			
30								

BENNETT & WILLIAMS, INC
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: GMW10A
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 9/11/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION :210.4
CASING ELEVATION : 211.8

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
					NO SAMPLES WERE TAKEN. LOG IS EXTRAPOLATED FROM BORING GMW10.			
					0.0-4.3' FILL : Red sandy clay, micaceous, dry			
5					4.3-5.3' Dark gray-black silty clay loam, organic rich, soft, roots, damp.			
					5.3-6.9' Gray-brown sand and clay, some silt, wet, non-plastic, medium stiff. Faint product odor.			
10								
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BORING: GMW11
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 10/11/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 202.0
CASING ELEVATION : 205.31

ORIGINAL (Red)

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	24"	W.H.		0.0-0.3' Black clay loam, little silt, roots, damp, soft. No product odor.			
	SS2	10"	6-12 -18		0.3-1.0' Gray-black clay and sand, some silt, low plasticity, wet, soft. No product odor.			
5	SS3	24"	13-16 -24		1.0-3.7' Brown-orange fine to coarse sand and clay, light gray-green and red mottling, damp, very stiff, friable. No product odor.			
	SS4	9"	19-36 -27		3.7-9.2' Brown clayey sand, some gravel. Mottled intervals (3") of gray-white and red brown, damp to wet. No product odor.			
	SS5		68-100X		Auger refusal on granite at 9.2'.			
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20								
25								
30								

BENNETT & WILLIAMS, INC
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: GMW11A
METHOD: 3.5" HOLLOW STEM AUGER
DATE : 9/13/85
PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 202.0
CASING ELEVATION : 205.0

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	4"	W.H.		0.0-0.5' Black clay loam, little silt, roots, damp. No product odor.			
	SS2	15"	2-2		0.5-4.0' Gray-black clay and sand, some silt, soft, low plasticity, wet. No product odor.			
	SS3	19"	6-9-15		4.0-5.0' Brown-orange fine to coarse sand and clay, some silt, very stiff, friable, light gray-green and red mottling, damp. No product odor.			
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ORIGINAL
(Red)

BORING: GMW12
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 10/10/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 209.4
CASING ELEVATION : 210.0

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	20"	3-2-3	0.0-0.5' Black-brown clay loam, some silt, organic rich, roots, dry.			
	SS2	13"	2-4-4	0.5-4.5' Light brown-gray clay and sand, some silt, medium stiff, dry. No product odor.			
5	SS3	11"	6-9-18	4.5-5.3' Light brown fine to coarse sand and clay, moist to dry, gray mottling, stiff. No product odor.			
	SS4	24"	10-13-13	5.3-9.2' Light gray-brown sand and clay, very stiff, friable, dry. No product odor.			
10	SS5	20"	5-6-9				
	SS6		3-6				
15				9.2-31.9' Light gray-white fine to coarse sand and silty clay, red-brown mottling, damp to moist, medium dense. No product odor.			
20							
25							
30				Auger refusal on granite at 31.9'.			

BORING: GMW13
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 10/7/85

PROJECT: *VIRGINIA WOOD PRESERVERS*
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.8
CASING ELEVATION : 208.8

ORIGINAL (Red)

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	12"	1-1-2		0.0-0.2' Dark brown-black clay loam, little silt, organic rich, dry.			
	SS2	24"	4-8-10		0.2-1.5' Light gray-brown clay and sand, some silt, soft, mottled, organic rich, dry. No product odor.			
5	SS3	24"	5-9-14		1.5-2.3' Yellow fine sand and clay, some silt, roots, medium stiff, damp. No product odor.			
	SS4	9"	8-13-16		2.3-5.8' Light gray-brown sand and clay, some silt, red-brown mottling, damp, very stiff. No product odor.			
10	SS5	21"	5-8-11		5.8-12.0' Light gray-brown fine to coarse sand and clay, some silt, friable, very stiff, damp. No product odor.			
	SH5				12.0-15.0' Brownish-gray silty clay and fine to coarse sand, soft, wet. No product odor.	MH	28	51
15	SS6	18"	3-5		15.0-42.0' Light gray-white fine to coarse sand and silty clay, red-brown mottling, wet, medium stiff to stiff. No product odor.			
20								
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BORING: GMW14 DATE: 9/16/85 PROJECT: VIRGINIA WOOD PRESERVERS
METHOD: 3.5" HOLLOW STEM AUGER LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 213.0
CASING ELEVATION : 215.7

ORIGIN
(Red

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	12"	9-13-12			
	SS2	15"	4-7-10			
5	SS3	20"	7-8-12			
	SS4	24"	16-16-19			
10	SS5	18"	6-9			
15	SS6	18"	7-9			
	SH3	14"		SC	16	35
20	SS7	16"	28-45-36			
	SS8	6"	36-100			
25						
30						

SOIL DESCRIPTION

0.0-0.3' Dark brown-black clay loam and sand, dry

0.3-1.3' Brown-red fine to medium clay and sand, very stiff, dry, white-gray mottling. No product odor.

1.3-1.8' Black sand, uncohesive, asphalt, dry.

1.8-4.3' Light gray-brown fine to coarse sand and clay, red-brown mottling, very stiff, friable, damp. Trace gravel at 3.8'. No product odor.

4.3-14.0' Light gray-white sand and clay, some silt trace gravel, red-brown mottling, loosely cemented, dry todamp, hard. No product odor.

14.0-23.9 Gray-white fine to coarse sand and silty clay, red-brown mottling, damp, dense to very dense. Wet at 19.0'. No product odor.

Auger refusal on granite at 23.9'.

AR100394

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: A
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 9/13/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION :203.8

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	12"	1-1-5		0.0-0.5' Dark brown clay loam, little silt, trace sand, soft, roots, non-plastic, wet. No product odor.			
	SS2	12"	4-5-7		0.5-3.0' Gray-black sandy silt, some clay, low plasticity, wet, medium stiff, trace gravel. No product odor.			
5	SS3	12"	7-10-14		3.0-4.0' Light brown clay and sand, some silt, stiff, plastic, damp. No product odor.			
					4.0-6.0' Brown-orange fine to coarse sand and clay, light gray-green and red mottling, damp, very stiff. No product odor.			
10								
15								
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BENNETT & WILLIAMS, INC
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: BS
DATE: 11/6/85
PROJECT: VIRGINIA WOOD PRESERVERS
METHOD: 3.5" HOLLOW STEM AUGER
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 210.4

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	14"	5-8-10		0.0-1.0' FILL. Gray-black sand and gravel.	CL	8	21
	SS2	24"	13-19-32		1.0-2.7' Light brown clay and sand, some silt, very stiff, dry, semi-plastic. No product odor.			
					2.7-4.0' Light brown sand and clay, some silt, trace gravel, hard, friable, some red and white mottling, dry. No product odor.			
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100597

(Rev)

BORING: CS
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 11/6/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 210.2

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	19"	18-16 -23		0.0-1.1' FILL. Gray-black sandy gravel and clay, dry.			
	SS2	11"	3-4-4		1.1-3.4' Brown-black fine to medium clay and sand, some gravel, damp, medium stiff. Strong product odor.			
5	SS3	18"	2-2			ML	N/P	46
	SS4	18"	8-21		3.4-4.2' Light gray silty clay, wet, medium stiff. Dark brown non-aqueous phase liquid in some pore spaces. Strong product odor.			
10					4.2-6.1' Orange-brown fine to medium sand and clay, gray mottling, soft, wet, non-plastic. Dark brown non-aqueous phase liquid in some pore spaces, and on split spoon sampler. Strong product odor.			
15					6.1-7.0' Light gray fine to coarse sand and clay, trace gravel, red mottling, damp, friable, hard. No product visible in pores. Product odor.			
20								
25								
30								

BENNETT & WILLIAMS, INC
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: DS
METHOD: 3.5" HOLLOW STEM AUGER
DATE: 11/6/85
PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.8

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	17"	7-6-6		0.0-1.0' Brown-orange clay and sand, some silt, damp, stiff. No product odor.			
	SS2	24"	4-6-21		1.0-3.5' Orange-brown fine to medium sand and clay, gray mottling, stiff, damp. No product odor. Wet at 2.6'.			
5					3.5-4.0' Light brown, yellow, and red fine to coarse sand and clay, damp to dry, hard, friable. Faint product odor.			
10								
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100399

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: ES
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 11/6/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SURFACE ELEVATION : 208.0 / SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	11"	4-5-6		0.0-0.7' Light brown clay and sand, wood chips, roots, stiff, dry. No product odor.			
			10-15					
	SS2	9.5"	-25		0.7-3.2' Orange-brown sand and clay, semi-plastic, very stiff, dry. No product odor.			
5					3.2-4.0' Light brown fine to coarse sand and clay, friable, hard, dry. No product odor.			
10								
15								
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100400

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: FS
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 11/7/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.5

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	14"	8-7-7		0.0-1.1' FILL : Black clayey sand and gravel, dry.			
	SS2	24"	1-3-4		1.1-2.4' Dark gray fine to medium clay and sand, stiff, green and red mottling, dry. Product odor. Orange-brown at 2.0'.			
5	SS3	14"	12-29		2.4-3.8' Brown-gray sand and clay, soft, wet. Dark brown non-aqueous phase liquid in some pore spaces. Strong product odor.			
10					3.8-4.6' Light brown-gray fine to medium sand and clay, friable, very stiff, damp, gray mottling. Dark brown non-aqueous phase liquid in some pore spaces. Strong product odor.			
15					4.6-5.5' Light gray-brown fine to coarse sand, some clay, hard, friable, loosely cemented, damp. Product odor.			
20								
25								
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100401

BONNOLL & WILLIAMS, INC.
CONSULTING GEOLOGISTS

BORING: GS	DATE : 11/7/85	PROJECT: VIRGINIA WOOD PRESERVERS
METHOD: 3.5" HOLLOW STEM AUGER		LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 208.9

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	9"	20-11-12		0.0-1.0' Black clay loam, some silt, trace gravel, dry.			
	SS2	15"	5-9-14		1.0-2.6' Dark brown fine to medium clay and sand, very stiff. Damp and soft at 2.0'. Strong product odor.			
5	SS3	24"	11-15-15		2.6-3.5' Orange-brown fine to coarse sand and clay, some silt, very stiff, damp, gray mottling. Strong Product odor.			
	SS4	24"	7-8-11		3.5-6.3' Light gray-white fine to coarse sand and clay, some silt, hard, damp to dry, loosely cemented, friable. At 4.0', dark brown non-aqueous phase liquid in some pore spaces and on spoon.			
10					6.3-8.0' White-gray fine to coarse sand and silty clay, red-brown mottling, damp to moist, medium dense. Dark brown non-aqueous phase liquid in some pore spaces. Strong product odor.			
15								
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100402

BORING: HS
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 11/7/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 209.7

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	15"	12-17-19		0.0-0.7' FILL : Black sandy clay, trace gravel, dry.			
	SS2	24"	1-4-7		0.7-2.0' Brown clay and sand, some gravel, very stiff, gray mottling, dry. No product odor.			
5	SS3	15"	7-19-21		2.0-3.4' Orange-brown sand and clay, some silt, soft, damp to wet, non-plastic. Faint product odor.	CL	12	22
10					3.4-4.1' Brown-gray clay and sand, some silt, stiff, damp to wet, plastic, red and orange mottling. Faint product odor.			
					4.1-5.2' Yellow-brown clay, some silt, little sand, medium stiff, wet, plastic. No product odor.			
15					5.2-6.0' Light gray-brown fine to coarse sand and clay, little gravel, hard, loosely cemented, friable, some red and orange mottling. No product odor.			
20								
25								
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BORING: I
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 11/8/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION: 213.1

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY.	LIQUID LIMIT
	SS1	15"	3-3-7		0.0-1.2 Dark brown clay loam, roots.	CL	7	21
	SS2	24"	5-7-8		1.2-1.9' Dark gray clay and sand, some silt, stiff, damp. No product odor.	SM	3	34
5	SS3	14"	8-15-14		1.9-5.7' Light gray sand and clay, some silt, stiff, damp. Some wet seams and gray mottling from 3.3-5.7'. No product odor.			
	SS4	24"	11-20-21		5.7-6.0' Gray medium to coarse sand, some silt, little clay, medium stiff, wet. No product odor.			
10					6.0-8.0' Gray-white fine to coarse sand and clay clay, trace gravel, hard, loosely cemented, friable, damp. No product odor.			
15								
20								
25								
30								

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL (Red)

BORING: JS
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 11/8/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION: 205.5

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	17"	5-6-6		0.0-1.1' Black clay loam, trace gravel.			
	SS2	22"	10-19-16		1.1-3.0' Brown-gray clay and sand, some silt, stiff, semi-plastic, dry. No product odor.			
5	SS3	19"	8-14-13		3.0-4.5' Light gray fine to coarse sand and clay, some silt, friable, dry to damp, very stiff. No product odor.	ML	N/P	32
					4.5-6.0' Light gray clay and fine to coarse sand, some silt, damp, stiff. No product odor.			
10								
15								
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100405

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL (Red)

BORING: KS
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 11/8/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 213.1

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND
	SS1	11"	17-12-15	
	SS2	24"	6-10-15	
5	SS3	24"	14-25-28	
10				
15				
20				
25				
30				

SOIL DESCRIPTION

SOIL CLASSIF. | PLASTICITY | LIQUID LIMIT

0.0-0.7' FILL. Black sand and gravel, some clay, dry.

0.7-1.2' Light brown-orange sand and silt, some gravel very stiff, dry. No product odor.

1.2-2.2' Dark gray clay and sand, some silt, very stiff, gasoline odor, dry.

2.2-4.2' Orange-gray clay and sand, some silt, damp stiff. Gasoline odor.

4.2-6.0' Brown-gray fine to medium sand, some clay, little silt, damp, hard, friable. Gasoline odor.

100406

BENNETT & WILLIAMS, INC
CONSULTING GEOLOGISTS

ORIGINAL
(Red)

BORING: L
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 11/8/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.6'

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	17"	1-2-2		0.0-0.6' Black clay loam, organic rich, roots, damp.	CL	10	35
	SS2	16"	2-4-6		0.6-1.2' Light brown-orange sand and clay, damp, soft. No product odor.	ML	4	35
5	SS3	18"	4-8-10		1.2-2.7' Gray-brown clay and silt, little sand, wet, semi-plastic, soft. No product odor.			
					2.7-4.0' Light gray clay and silt, trace sand, wet, stiff. No product odor.			
10								
15								
20								
25								
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130407

CONSULTING GEOLOGISTS

ORIGINAL (Red)

BORING: MS
METHOD: 3.5" HOLLOW STEM AUGER

DATE: 11/11/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 206.2'

DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	4"	2-4-2		0.0-0.6' Black clay loam, roots, dry. Product odor.			
	SS2	17"	6-29 -37		0.6-2.0' Brown-yellow clay and sand, soft, wet. No product odor.	CL	7	20
						SM	N/P	36
5					0.6-3.4' Light brown sand and clay, some silt, stiff, damp. No product odor.			
					3.4-4.0' Light gray-white fine to coarse sand, some clay and silt, hard, dry, friable, loosely cemented. No product odor.			
10								
15								
20								
25								
30								

100408

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL (Red

BORING: NS
METHOD: 3.5" HOLLOW STEM AUGER

DATE : 11/11/85

PROJECT: VIRGINIA WOOD PRESERVERS
LOCATION: HENRICO CO., VIRGINIA

SURFACE ELEVATION : 207.5

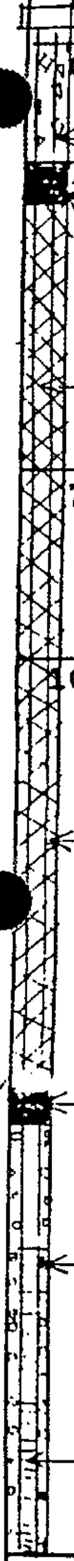
DEPTH (FT)	SAMPLE	RECOVERY	PENETRATION EFFORT (6")	LEGEND	SOIL DESCRIPTION	SOIL CLASSIF.	PLASTICITY	LIQUID LIMIT
	SS1	12"	13-6-5		0.0-1.4' FILL. Black and gray sand and gravel, some clay.	ML	N/P	15
	SS2	24"	2-5-13		1.4-2.2' Orange-brown clay and sand, some silt, dry, stiff. No product odor.	CL	5	19
5	SS3	22"	8-10 -20		2.2-3.4' Orange-brown clay and sand with light gray fine to coarse sand and clay intervals, some silt, damp to wet, stiff, non-plastic. No product odor.	ML	N/P	25
10					3.4-4.3' Brown sand and clay, some silt, very stiff, damp. No product odor.			
					4.3-4.8' Light brown-yellow clay and sand, some silt, wet semi-plastic, very stiff. No product odor.			
15					4.8-6.0' Light gray-white clay with fine to coarse sand, some silt, loosely cemented, damp, hard No product odor.			
20								
25								
30								

100409

Project Virginia Wood Preserving - Rentokil | Boring No. GMW-1 | Sheet 1 of 1

Location Peyton Street & Oakview Avenue, Henrico County, Va. | Date of Boring 3/21/85

Surface Elevation Ft. | Loged By: WWH | Job No. 85-02-13



Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	FILL MATERIAL- Damp brown clayey SAND No Product Odor CONCRETE	1	0.0	1.5	6-8-6
2.0	Wet dark gray silty CLAY with organic material Strong Product Odor BENTONITE SEAL 2" PVC. RISER SCHEDULE 40	2	2.0	3.5	1-2-1
		3	4.0	5.5	1-1-1
7.0	Damp brown & strong brown clayey SAND Product Odor				
10.0	Granite Residuum - Damp yellowish brown & gray micaceous silty clayey SAND Slight Product Odor BENTONITE-SOIL GROUT	4	9.0	10.5	4-14-22
		5	14.0	15.5	4-9-14
	BENTONITE SEAL GRAVEL PACK	6	19.0	20.5	10-27-45
	2" SCREEN PVC. SCH. 40 .010 SLOTS (5' LENGTH)	7	24.0	24.2	100
24.2	Bottom of Hole				

Ground Water Data: Ground Water Contact 14.0

Water level is 3.0 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK
GEOTECHNICAL SERVICES, IN
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 inches.

GMW-1 (1)

100410

TEST BORING RECORD

Project Virginia Wood Preserving - Rentokil | Boring No. GMW-2 | Sheet 1 of 1

Location Peyton Street & Oakview Avenue, Henrico County, Va. | Date of Boring 3/25/85

Surface Elevation ____ Ft. | Logged By: WWH | Job No. 85-02-13

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	Damp yellow brown red & gray sandy CLAY No Product Odor CONCRETE	1	0.0	2.0	4-4-4-5
	BENTONITE SEAL 2" PVC SCH. 40 RISER	2	2.0	4.0	7-19-26-43
4.0	Damp gray & yellow brown clayey SAND No Product Odor	3	4.0	6.0	7-23-34-34
	Trace of Quartz Fragments - 7.0' BENTONITE SOIL GROUT	4	6.0	8.0	15-31-38-32
8.0	Granite Residuum - Damp gray to gray & yellow brown sandy CLAY to clayey SAND (Large Fragments of weathered to unweathered GRANITE)	5	8.0	10.0	6-13-16-20
	No Product Odor BENTONITE SEAL	6	10.0	12.0	5-8-11-14
	GRAVEL PACK	7	12.0	14.0	6-9-10-13
	2" PVC SCH. 40 SCREEN (.010) (5' LENGTH)	8	14.0	16.0	5-11-15-16
		9	18.0	18.1	50
18.1	Bottom of Hole				

Ground Water Data: Ground Water Contact 18.0

Water level is 7.1 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC.
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches

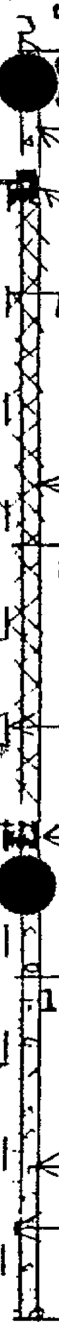
T00410A GMW-2 (7)

TEST BORING RECORD

Project Virginia Wood Preserving - Rentokil | Boring No. GMW-3 | Sheet 1 of 1

Location Peyton Street & Oakview Avenue, Henrico County, Va. | Date of Boring 3/25/85

Surface Elevation Ft. Loged By: WWH | Job No. 85-02-13



Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	Damp black silty SAND				
0.7	Damp yellow brown sandy CLAY Faint Product Odor CONCRETE	1	0.0	2.0	8-13-8-5
	BENTONITE SEAL	2	2.0	4.0	2-8-12-17
4.0	Damp yellow brown gray & red clayey SAND Product Odor	3	4.0	6.0	8-13-20-20
	BENTONITE-SOIL GROUT	4	6.0	8.0	6-16-16-16
8.0	Granite Residuum - Damp gray red & yellow brown to gray sandy CLAY Product Odor	5	8.0	10.0	5-11-17-21
	2" SCH. 40 PVC RISER	6	10.0	12.0	5-7-11-13
	BENTONITE SEAL	7	12.0	14.0	4-8-11-13
15.0	Disintegrated Granite - Damp brown yellow micaceous clayey SAND to silty SAND	8	14.0	16.0	3-6-8-10
	Faint Product Odor GRAVEL PACK	9	16.0	18.0	2-7-12-20
	2" PVC SCREEN (.010) SCHEDULE 40 (5' LENGTH)	10	19.0	20.4	5-25-100
20.4	Bottom of Hole				

Ground Water Data: Ground Water Contact 11 & 19

Water level is 3.8 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK
GEOTECHNICAL SERVICES, INC
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

100411

GMW-3 (15)

Project Virginia Wood Preserving - Rentokil | Boring No. GMW-4 | Sheet 1 of 1

Location Peyton Street & Oakview Avenue, Henrico County, Va. | Date of Boring 3/25/85

Surface Elevation Ft. | Loged By: WWH | Job No. 85-02-13

Depth Ft	Boring Log & Notes	Sampling Data No.	From	To	Blows*
0.0	Damp black silty SAND				
0.5	Damp gray silty SAND CONCRETE	1	0.0	2.0	2-6-15-19
2.0	Damp gray & yellow brown clayey SAND BENTONITE SEAL (0.5')	2	2.0	4.0	9-12-15-21
4.5	Fragipan - Dry gray cemented silty fine grained SAND	3	4.0	5.2	6-37-63
6.0	Granite Residuum - Disintegrated Granite Light gray micaceous clayey SAND to silty SAND 2" PVC SCH. 40 RISER	4	6.0	8.0	16-21-21-17
	BENTONITE-SOIL GROUT	5	8.0	10.0	6-12-20-25
	(0.5') BENTONITE SEAL	6	10.0	12.0	14-18-25-20
	GRAVEL PACK	7	14.0	15.5	12-15-19
15.5	Weathered Granite - Damp brown yellow micaceous silty SAND 2" PVC SCH 40 SCREEN (.010) (5' LENGTH)	8	19.0	19.8	32-68
19.8	Bottom of Hole **No Product Odor				

Ground Water Data: Ground Water Contact 8.0

Water level is 3.2 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC. RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

GMW-4 (14)

Project: Virginia Wood Preserving - Rentokil | Boring No. GMW-5 | Sheet 1 of 1

Location: Peyton Street & Oakview Avenue, Henrico County, Va. | Date of Boring 3/26/85

Surface Elevation Ft. | Loged By: WWH | Job No. 85-02-13

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	Damp yellow brown clayey SAND No Product Odor CONCRETE	1	0.0	2.0	9-15-14-18
2.0	Damp yellow brown sandy CLAY with trace of Quartz Fragments No Product Odor	2	2.0	4.0	7-10-19-31
	0.5' BENTONITE SEAL	3	4.0	6.0	10-20-27-30
6.0	Damp variegated sandy CLAY - red gray & yellowish brown No Product Odor	4	6.0	8.0	6-13-18-28
	BENTONITE SOIL GROUT	5	8.0	10.0	5-10-13-15
10.0	Granite Residuum - Damp variegated micaceous sandy silty CLAY - red gray & yellowish brown No Product Odor	6	10.0	12.0	3-5-6-10
	2" P.V.C. SCH. 40 RISER	7	12.0	14.0	3-5-8-8
	0.5' BENTONITE SEAL	8	14.0	16.0	2-6-6-7
19.0	Disintegrated Granite - Damp brown & yellowish brown micaceous silty SAND No Product Odor	9	19.0	20.5	1-2-4
	GRAVEL PACK 2" P.V.C. SCH. 40 SCREEN (.010) (5' LENGTH)				
25.7	Bottom of Hole	10	24.0	25.5	16-23

Ground Water Data: Ground Water Contact 19.0

Water level is 6.9 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

GMW-5 (20)

100413

TEST BORING RECORD

Project Virginia Wood Perserving - Rentokil | Boring No. B-2 | Sheet 1 of 1

Location Peyton St. & Oakview Ave., Henrico County, Va. | Date of Boring 2-19-85

Surface Elevation Ft. | Loged By: WED | Job No. 85-02-13

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	FILL: Variegated (yellow brown red & gray) micaceous clayey sandy SILT	1	0.0	2.0	3-5
2.8	Damp to wet variegated brown gray & yellow sandy SILT Paint Product Odor	2	2.0	4.0	6-12
6.0	FRAGIPAN - Dry gray silty SAND loosely cemented No Product Odor	3	5.0	7.0	8-10
		4	10.0	12.0	13-18
11.5	Damp yellow gray sandy plastic SILT No Product Odor				
16.0	Disintegrated GRANITE - Dry to damp brown clayey sandy micaceous SILT	5	15.0	17.0	7-20
			20.0	20.5	10
20.5	Weathered GRANITE	6	20.5	21.0	46
		7	21.0	21.1	54
21.1	Slightly weathered GRANITE BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact 14.5

Water level is 3.7 ft. below ground surface 24.0 hrs. after completion.

Cave in at 11.9 ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, IN RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-2

100414

TEST BORING RECORD

Project Virginia Wood Perserving - Rentokil | Boring No. B-13 | Sheet 1 of 1

Location Peyton St. & Oakview Ave., Henrico County, Va. | Date of Boring 2-19-85

Surface Elevation Ft. | Loged By: WED | Job No. 85-02-13

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	Wet dark brown CLAY				
1.0	FRAGIPAN - HARDPAN - Dry gray cemented silty fine grained SAND No Product Odor	1	0.0	2.0	5-75
		2	2.0	2.8	100
3.5	Dry yellow brown sandy CLAY No Product Odor				
		3	4.5	6.5	24-41
7.0	GRANITE RESIDUUM - Damp red brown sandy CLAY, transitioning to red brown clayey SAND Faint Product Odor				
10.0	Disintegrated GRANITE - Dry clayey fine grained SAND Faint Product Odor	4	9.5	11.5	8-29
13.5	GRANITE RESIDUUM - Gray sandy CLAY Product Odor		14.5	15.0	5
15.0	Slightly weathered GRANITE	5	15.0	15.1	100
15.1	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact None
Water level is 1.2 ft. below ground surface 24.0 hrs. after completion.
Cave in at 7.0 ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC.
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-13

100415

TEST BORING RECORD

Project: Virginia Wood Perserving - Rentokil	Boring No. B-18 Sheet 1 of 1
Location: Peyton St. & Oakview Ave., Henrico County, Va.	Date of Boring 2-19-85
Surface Elevation Ft. Loged By: WED	Job No. 85-02-13

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	FILL: Damp brown clayey SAND Strong Product Odor	1	0.0	2.0	11-9
1.0	FILL: Damp yellow brown sandy CLAY Strong Product Odor				
2.5	Damp variegated sandy CLAY (yellow brown red & gray) Strong Product Odor	2	2.0	4.0	6-11
		3	4.5	6.5	12-21
		4	9.5	11.5	9-24
13.0	GRANITE RESIDUUM: Disintegrated GRANITE - Dry beige micaceous silty SAND Product Odor				
		5	14.5	16.5	22-82
16.0	Highly weathered to weathered GRANITE Product Odor				
		6	19.5	20.0	26
20.0	Weathered GRANITE		20.0	20.55	50
20.5	Slightly weathered GRANITE		20.55	20.6	50
20.6	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact 12.5
Water level is 0.9 ft. below ground surface 24.0 hrs. after completion.
Cave in at 12.3 ft below ground surface.

DVORAK
GEOTECHNICAL SERVICES, INC.
RICHMOND, VIRGINIA

B-18

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

100416

TEST BORING RECORD

Project Virginia Wood Preserving - Rentokil | Boring No. B-21 | Sheet 1 of 1

Location Peyton St. & Oakview Ave., Henrico County, Va. | Date of Boring 2-19-85

Surface Elevation Ft. | Loged By: WED | ORIGINAL | Job No. 85-02-13

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	FILL: Wet black-brown sandy CLAY				
1.0	Damp yellow brown sandy CLAY	1	0.0	2.0	4-8
3.0	Damp variegated sandy CLAY Product Odor	2	4.5	6.5	11-20
6.0	Wet gray mottled yellow & brown clayey SAND Product Odor				
8.5	Damp gray & yellow brown sandy CLAY No Product Odor	3	9.5	11.5	9-18
13.0	Damp to wet gray sandy plastic CLAY No Product Odor	4	14.5	16.5	5-8
18.0	Disintegrated granite Wet to damp gray to beige micaceous silty SAND No Product Odor	5	19.5 20.4	20.4	8 Refusal
20.4	Unweathered GRANITE BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact 18.0
Water level is 2.8 ft. below ground surface 24.0 hrs. after completion.
Cave in at 9.5 ft. below ground surface.

DVORAK
GEOTECHNICAL SERVICES, INC.
RICHMOND, VIGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-21

100417

TEST BORING RECORD

Project Parham Forest | Boring No. B-1 | Sheet 1 of 1

Location Peyton Street & Ackley Road, Henrico Co., Va. | Date of Boring 5/23/85

Surface Elevation Ft. | Loged By: WWH | Job No.

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	Damp gray sandy CLAY	1	0.0	1.5	1-1-1
		2	2.0	3.5	3-4-6
		3	4.0	5.5	4-10-16
		4	7.0	8.5	4-7-10
9.0	Damp gray & yellowish brown clayey SAND - disintegrated granite	5	9.0	10.5	4-10-12
		6	14.0	15.5	4-6-13
15.5	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact 12.0'

Water level is 3.5 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK
GEOTECHNICAL SERVICES, INC.
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-1

100418

Project Parham Forest			B No. B-2	Sheet 1 of 1
Location Peyton Street & Ackley Road, Henrico Co., Va.			Date of Boring	5/23/85
Surface Elevation Ft.	Loged By: WWH		Job No.	

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	ORGANIC TOPSOIL				
0.2	Damp gray sandy CLAY	1	0.0	1.5	1-1-1
		2	2.0	3.5	2-3-5
		3	4.0	5.5	3-6-9
7.0	Damp gray & yellowish brown sandy CLAY	4	7.0	8.5	5-13-12
		5	9.0	10.5	7-16-22
14.0	Yellowish brown & white silty clayey SAND - disintegrated granite	6	14.0	15.5	3-7-10
15.5	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact None
Water level is 1.3 ft. below ground surface 24.0 hrs. after completion.
Cave in at ____ ft. below ground surface.

DVORAK
GEOTECHNICAL SERVICES, INC.
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-2

100419

TEST BORING RECORD

Project	Parham Forest
Boring No.	B-3
Sheet	1 of 1
Location	Peyton Street & Ackley Road, Henrico Co., Va.
Date of Boring	5/23/85
Surface Elevation	Ft.
Logged By:	WWH
Job No.	

Depth Ft	Boring Log & Notes	Sampling Data No.	From	To	Blows*
0.0	Damp gray silty SAND	1	0.0	1.5	2-8-16
1.0	Damp gray sandy CLAY	2	2.0	3.5	10-16-32
4.0	Damp light gray silty SAND (HARDPAN)	3	4.0	4.6	40-60
		4	7.0	8.5	30-18-10
8.1	Damp gray clayey SAND	5	9.0	10.5	1-4-8
14.0	Damp variegated disintegrated GRANITE	6	14.0	15.5	6-17-40
15.5	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact None

Water level is 14.0 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC.
RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-3

100420

TEST BORING RECORD

Project: Parham Forest — Boring No. B-4 — Sheet 1 of 1

Location: Peyton Street & Ackley Road, Henrico Co., Va. — Date of Boring: 5/23/85

Surface Elevation: Ft. — Loged By: WWH — Job No.

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	ORGANIC TOPSOIL				
0.3	Damp gray silty SAND	1	0.0	1.5	1-3-8
2.0	Damp gray & yellowish brown clayey SAND	2	2.0	3.5	3-6-8
		3	4.0	5.5	7-9-12
6.0	Damp tan silty SAND (HARDPAN)	4	7.0	8.0	20-80
9.0	Damp yellowish brown sandy CLAY	5	9.0	10.5	5-12-20
14.0	Damp variegated disintegrated GRANITE	6	14.0	15.5	2-3-3
15.5	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact None

Water level is 12.0 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC. RICHMOND, VIRGINIA

B-4

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

100421

TEST BORING RECORD

Project Parham Forest — Boring No. B-5 — Sheet 1 of 1

Location Peyton Street & Ackley Road, Henrico Co., Va. — Date of Boring 5/23/85

Surface Elevation Ft. — Loged By: WWH — Job No.

ORIGINAL

Depth Ft	Boring Log & Notes	No.	From	To	Blows*
0.0	ORGANIC TOPSOIL				
0.2	Damp gray silty SAND (HARDPAN)	1	0.0	1.5	1-12-19
		2	2.0	3.1	13-32-68
		3	4.0	4.6	80-20
7.0	Damp variegated clayey SAND - disintegrated granite	4	7.0	8.5	2-3-5
		5	9.0	10.5	4-4-19
		6	14.0	15.5	8-14-15
15.5	BOTTOM OF HOLE				

Ground Water Data: Ground Water Contact 13.0'

Water level is 4.0 ft. below ground surface 24.0 hrs. after completion.

Cave in at ____ ft. below ground surface.

DVORAK GEOTECHNICAL SERVICES, INC. RICHMOND, VIRGINIA

*No. of Blows 140-lb. Hammer, 30-in. Fall, Required to Drive 2 in. O.D., 1.375 in I.D. Sampler 6 Inches.

B-5

100422

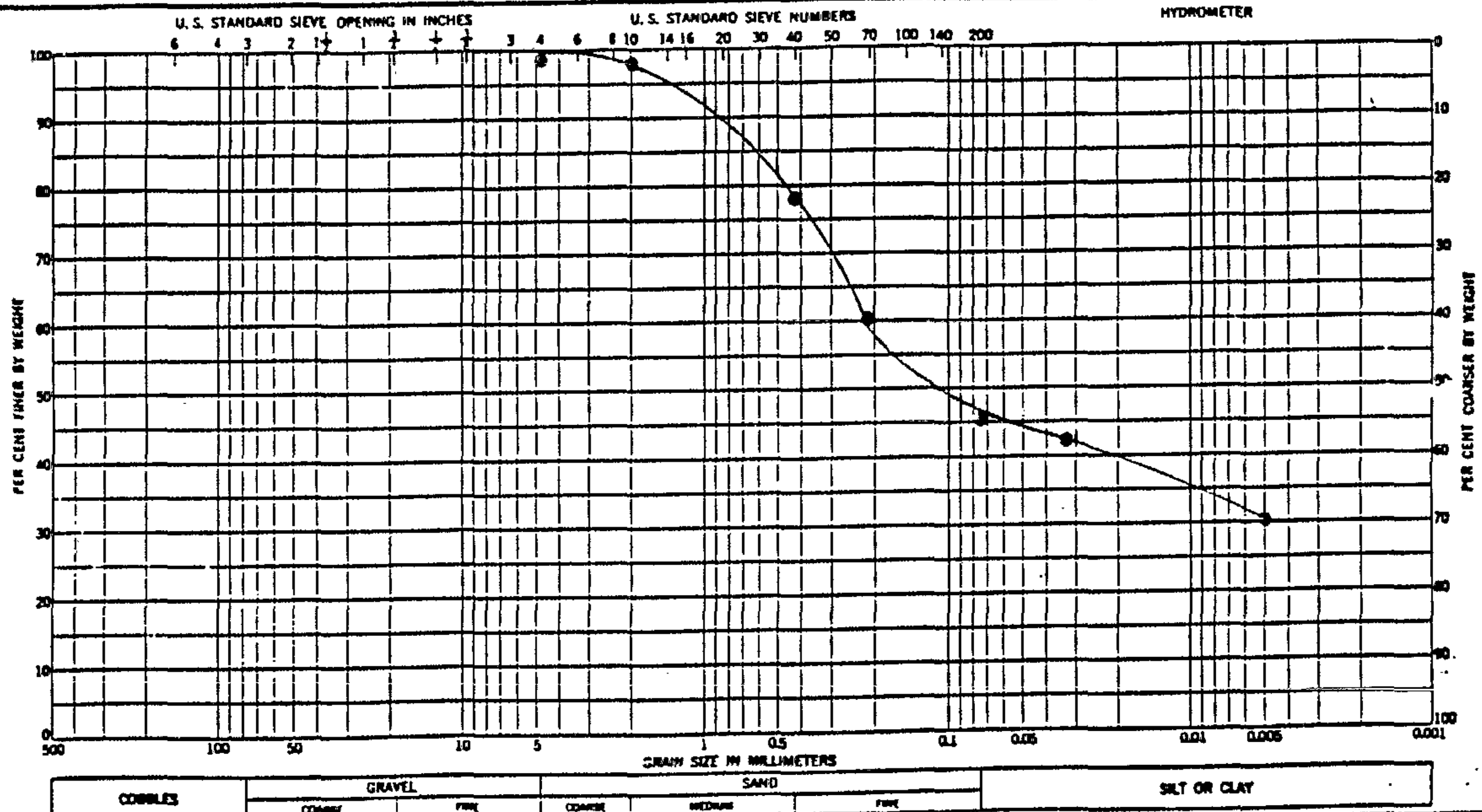
ORIGINAL (Red)

APPENDIX 2

Grain Size Distribution Graphs

100423

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	16.0-17.2	SC				

Project: Virginia Wood Preservers

Area: Henrico County, VA.

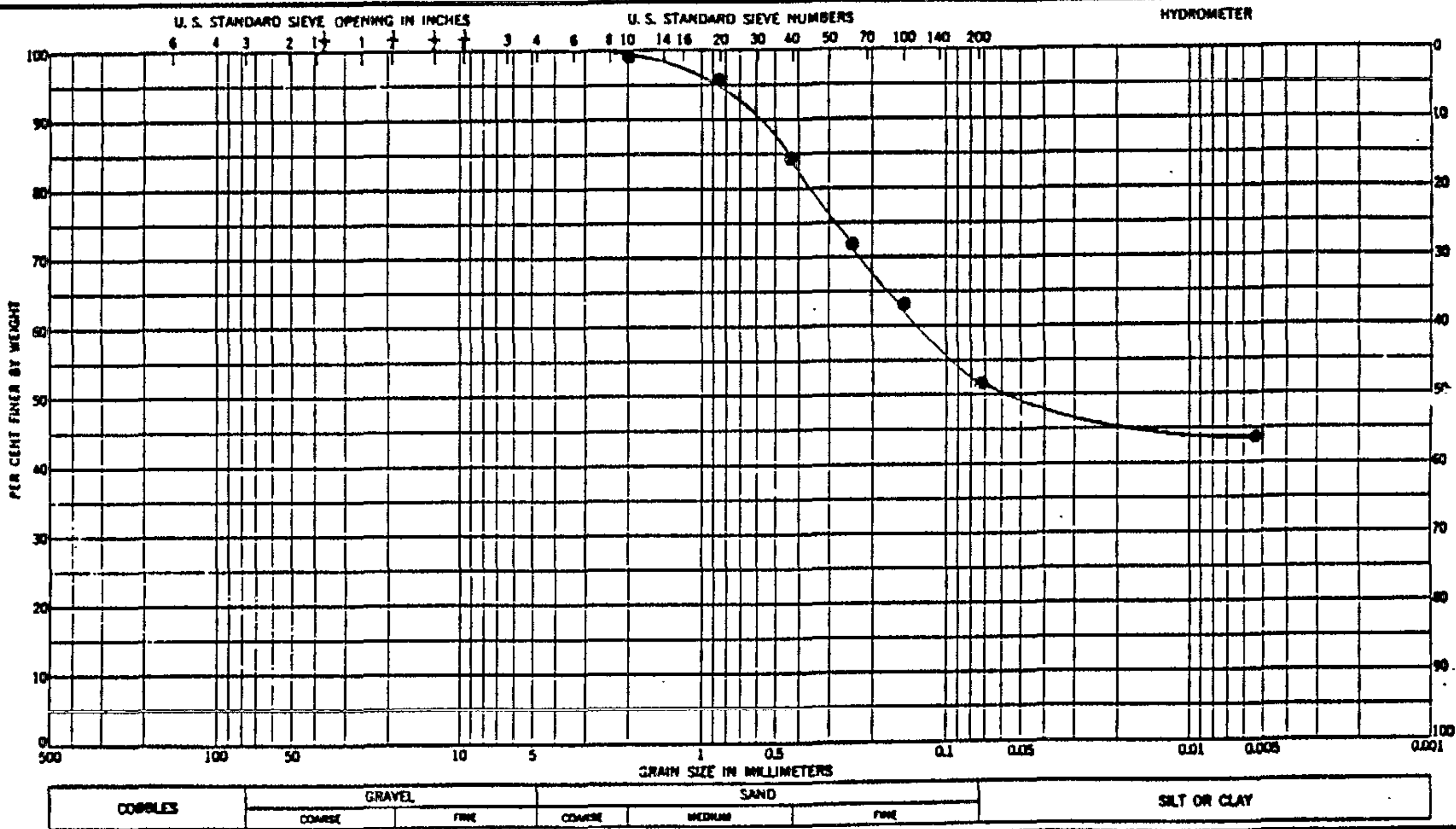
Boring No: CMW-14

Date: December, 1985

GRADATION CURVES

100424

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	48-53	CL-ML				

Project: Virginia Wood Preservers

Area: Henrico County, VA.

Boring No. NS

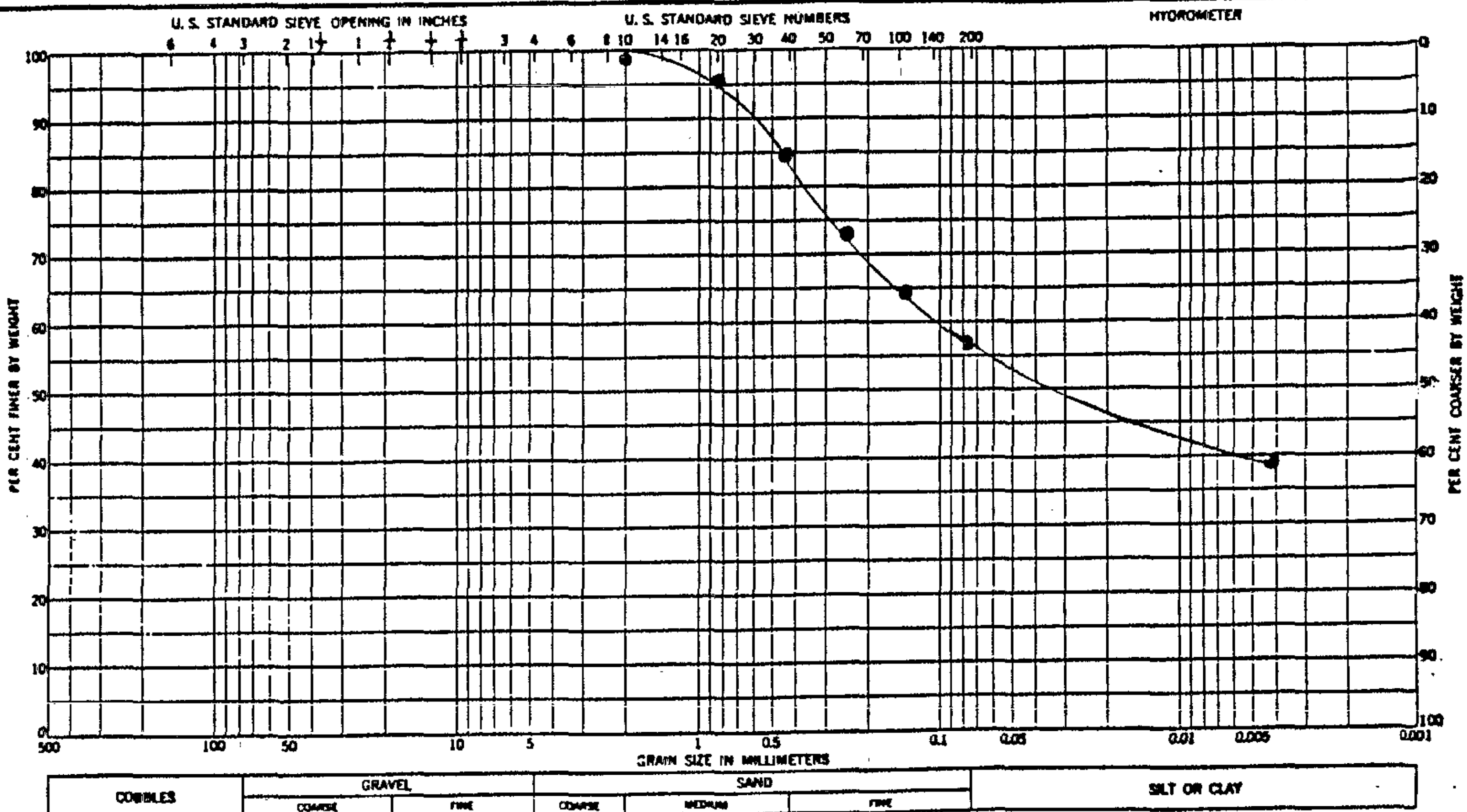
Date: December, 1985

GRADATION CURVES

ORIGINAL (Red)

100425

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	60-65	ML				

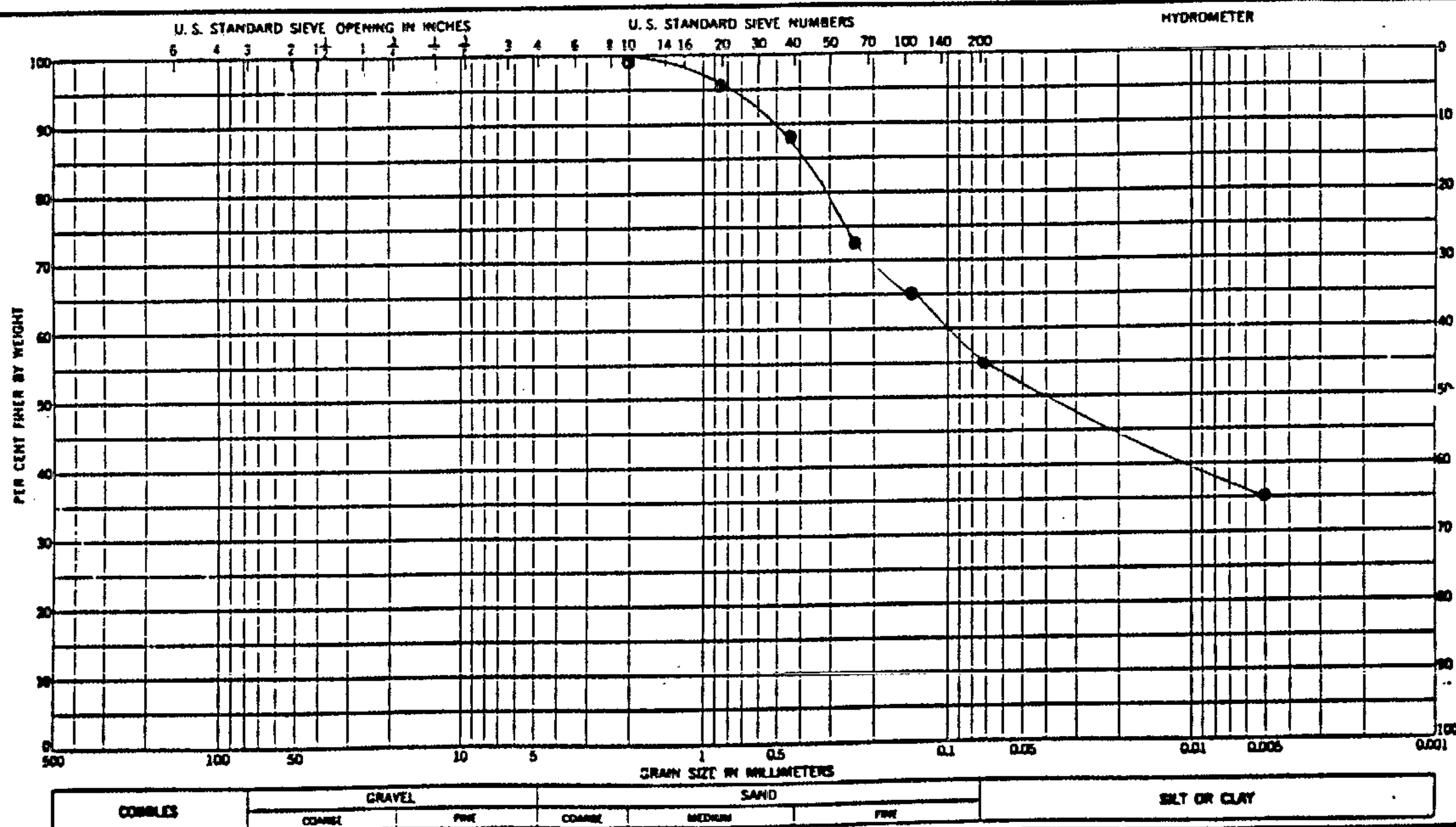
Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No.	NS
Date	December, 1955

GRADATION CURVES

ORIGINAL (Red)

100426

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	32-35	ML				

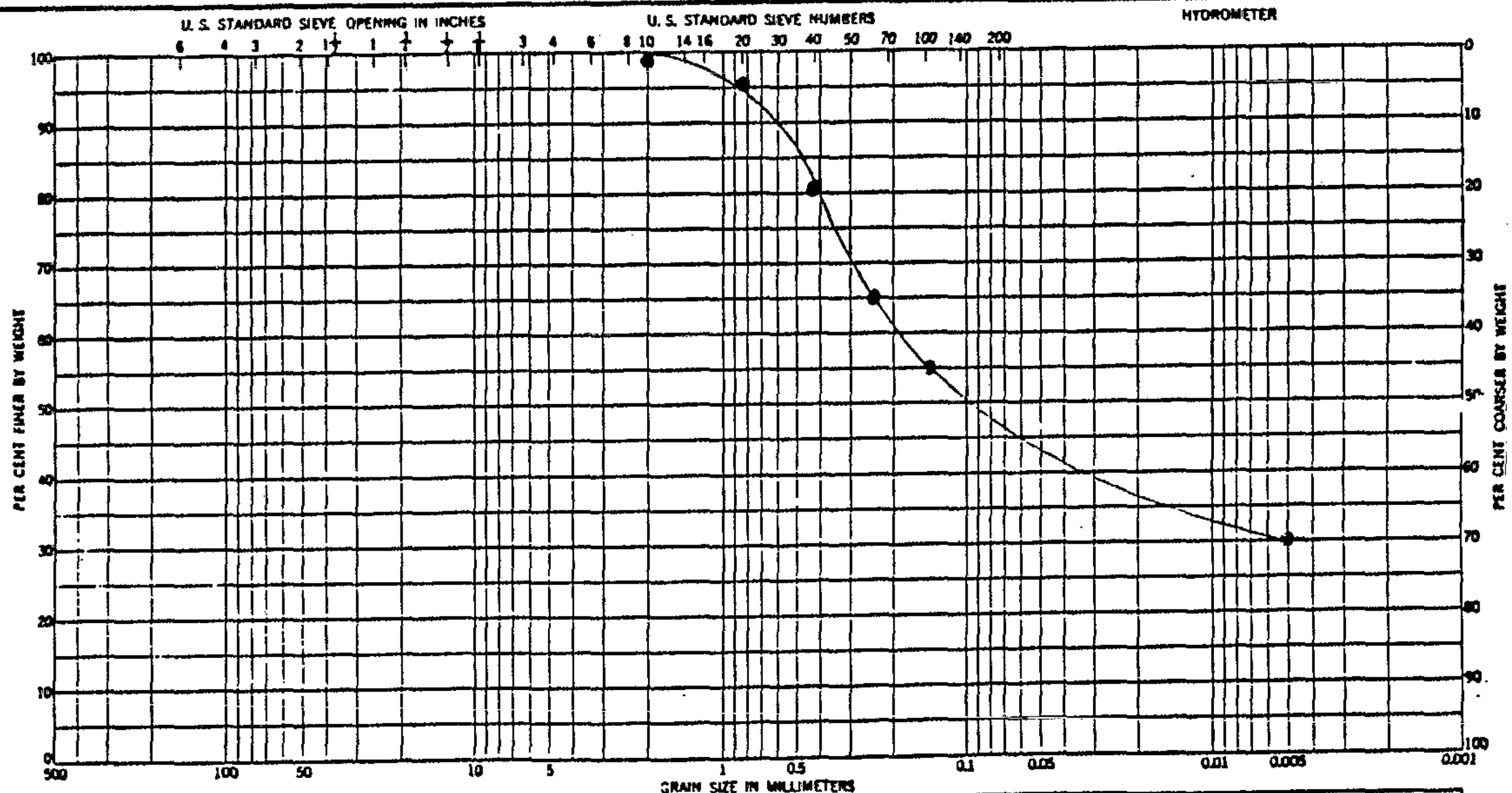
GRADATION CURVES

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No	NS
Date	December, 1995

ORIGINAL (Red)

100427

GRAIN SIZE DISTRIBUTION GRAPH



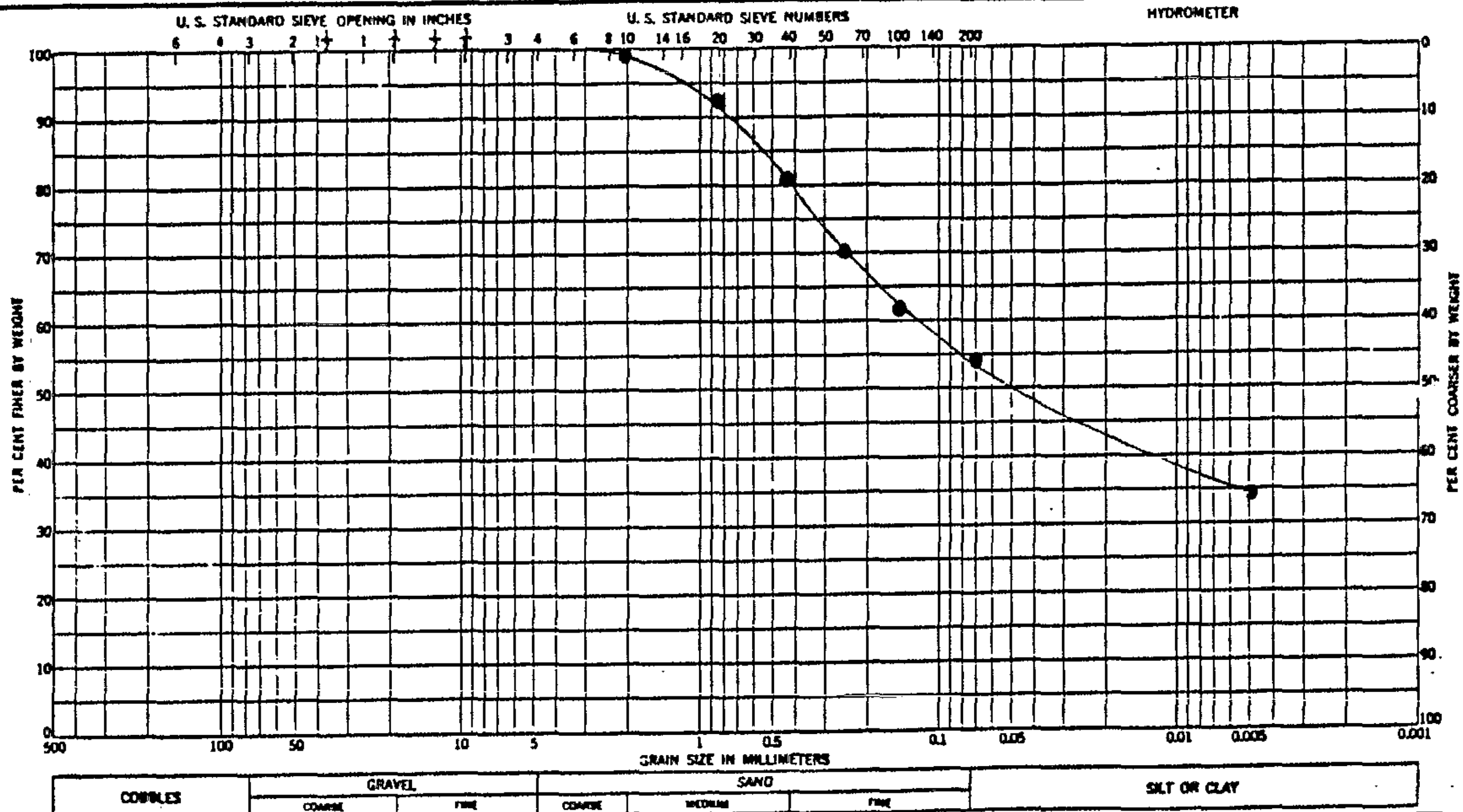
Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	41-46	SM				

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No.	MS
Date	December, 1985

GRADATION CURVES

100428

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	24-29	CL				

Project: Virginia Wood Preservers

Area: Henrico County, VA.

Boring No.: MS

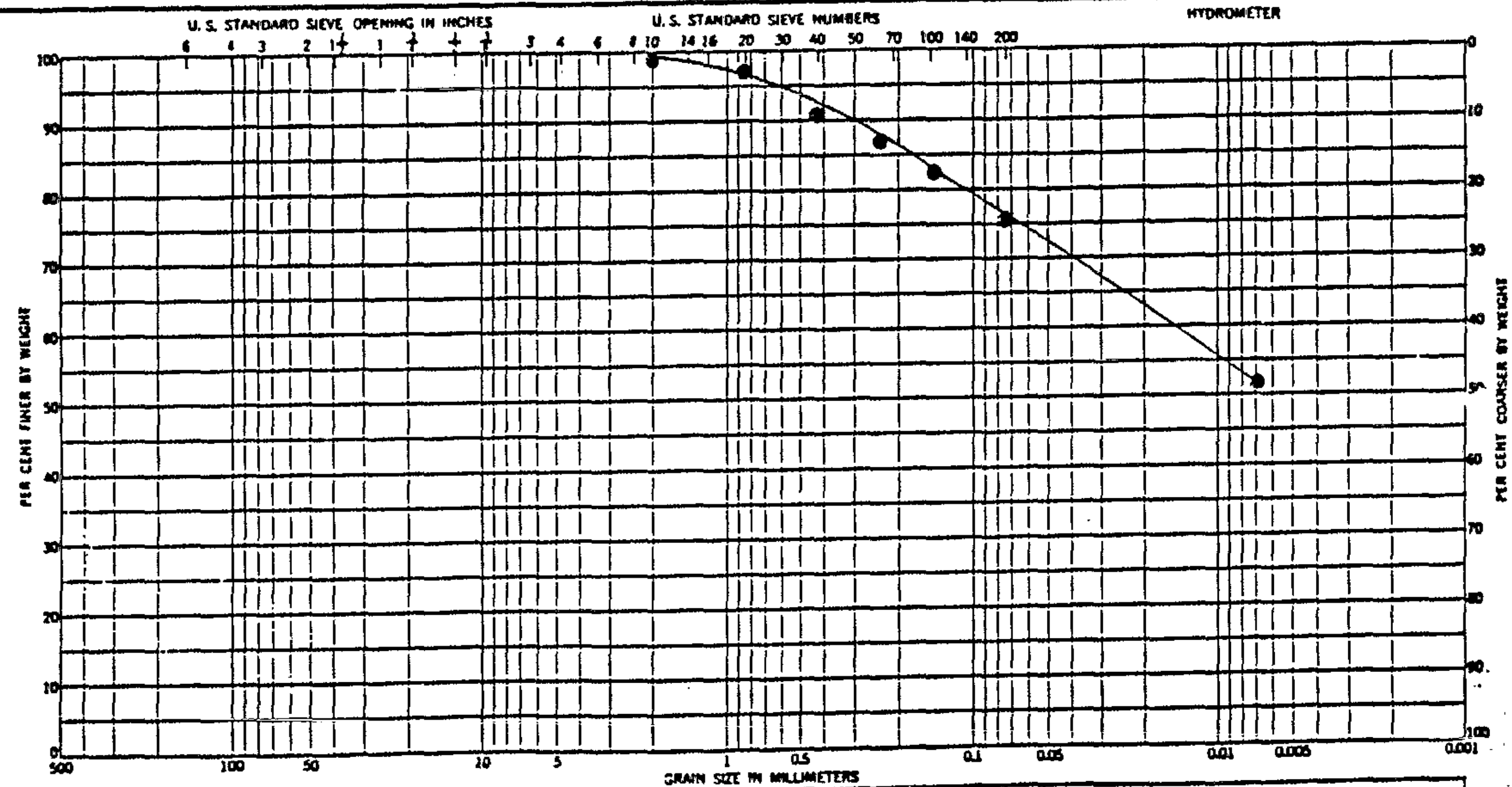
Date: December, 1935

GRADATION CURVES

ORIGINAL (Red)

100429

GRAIN SIZE DISTRIBUTION GRAPH



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	33-38	ML				

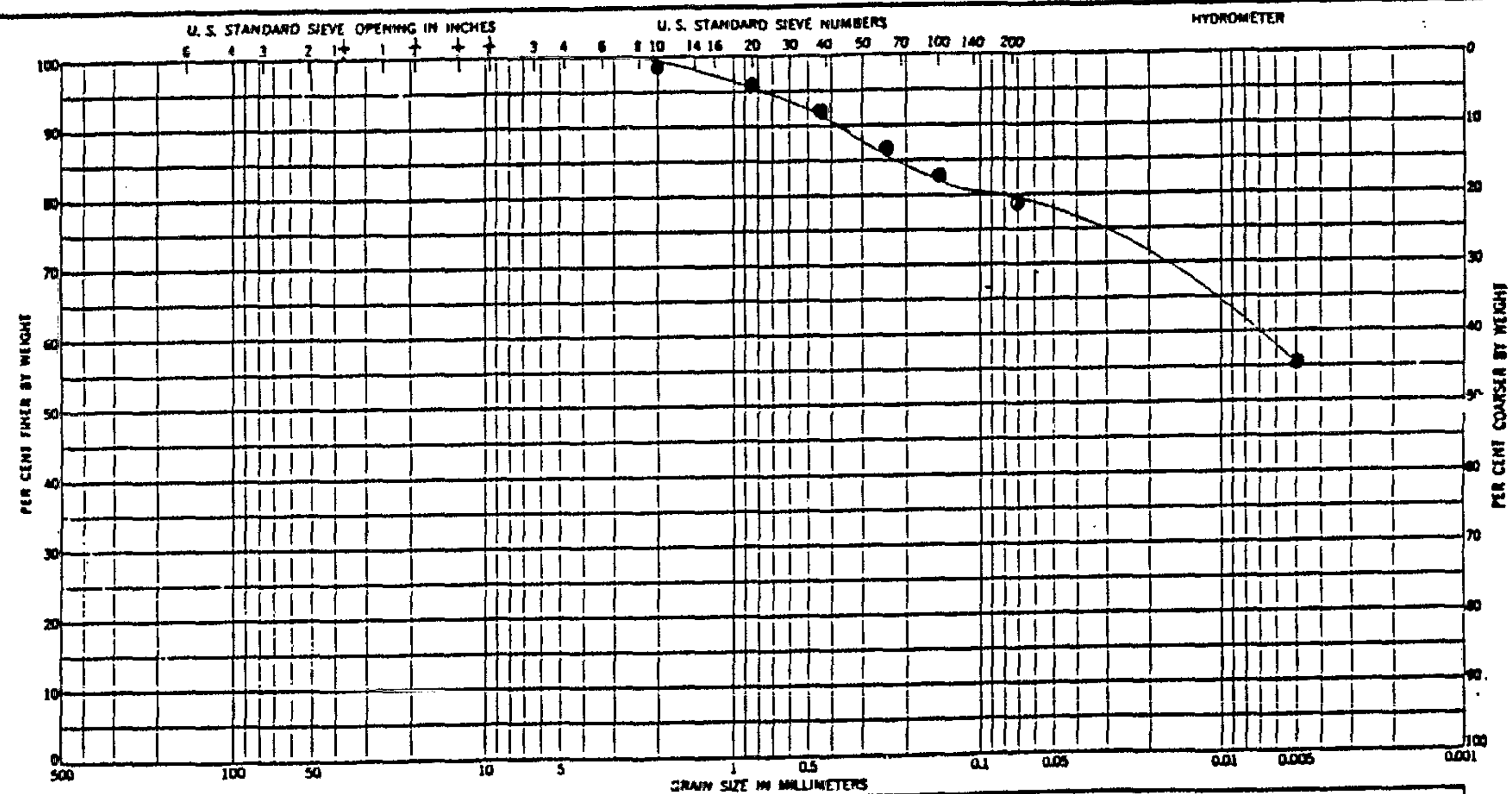
GRADATION CURVES

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No	L
Date	December, 1985

ORIGINAL (Red)

100430

GRAIN SIZE DISTRIBUTION GRAPH



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	17-23	CL				

Project: Virginia Wood Preservers

Area: Henrico County, VA.

Boring No: L

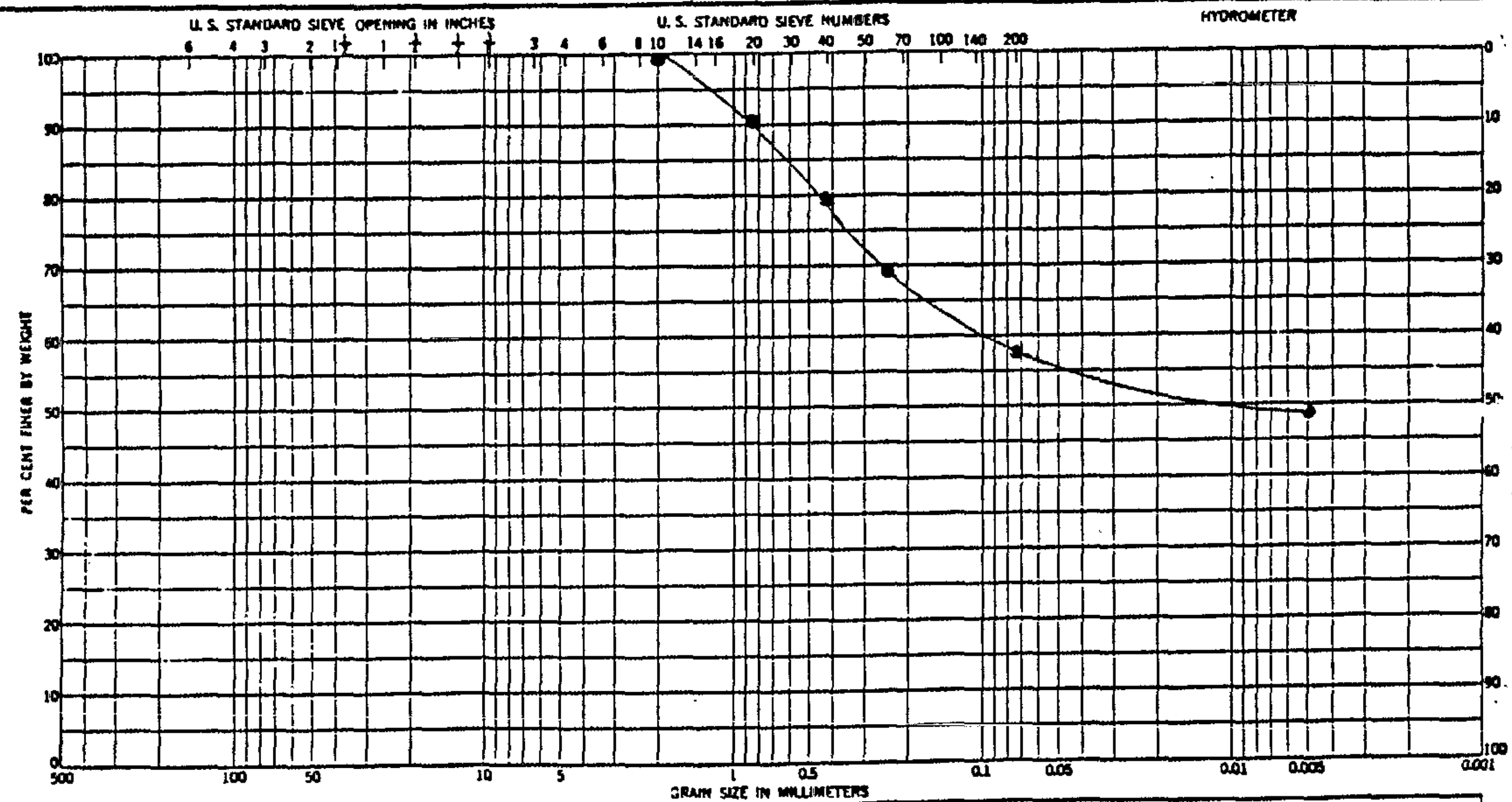
Date: December, 1985.

ORIGINAL (Red)

GRADATION CURVES

100431

GRAIN SIZE DISTRIBUTION GRAPH



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	68-70	ML				

GRADATION CURVES

Project: Virginia Wood Preservers

Area: Henrico County, VA.

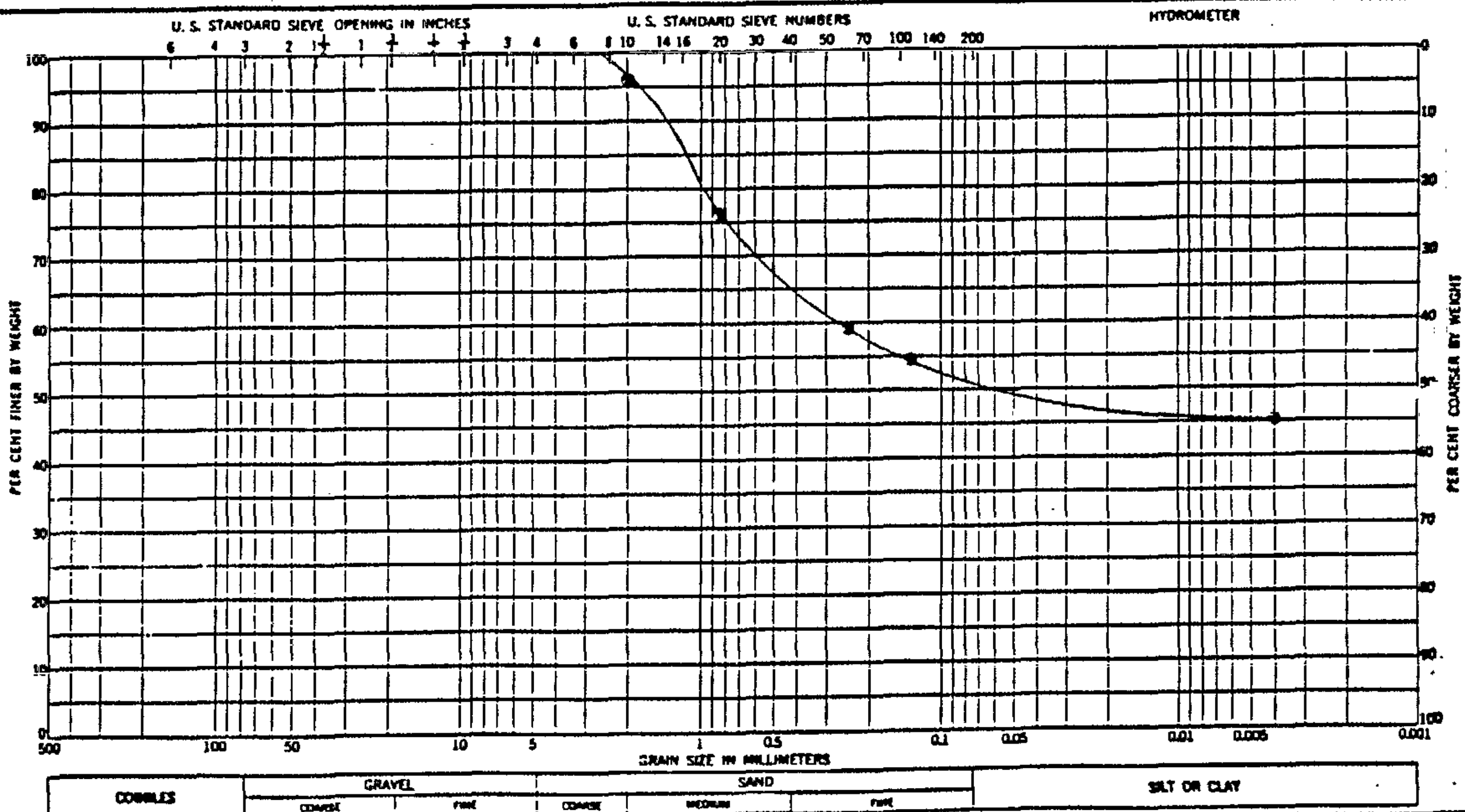
Boring No.: JS

Date: December, 1985

ORIGINAL (Red)

100432

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	34-37	SM				

GRADATION CURVES

Project: Virginia Wood Preservers

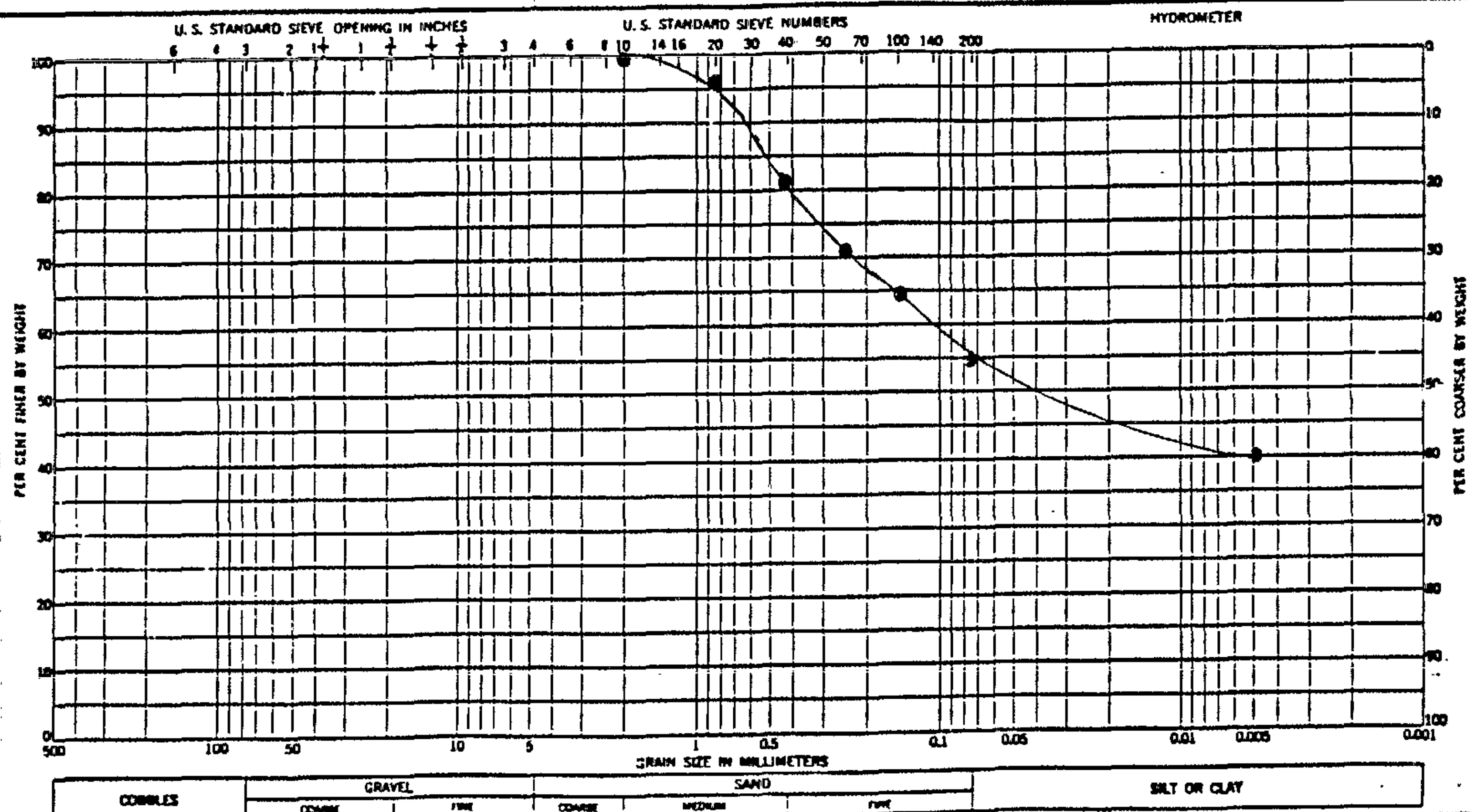
Area: Henrico County, VA.

Boring No: I

Date: December, 1985

100433

GRAIN SIZE DISTRIBUTION GRAPH



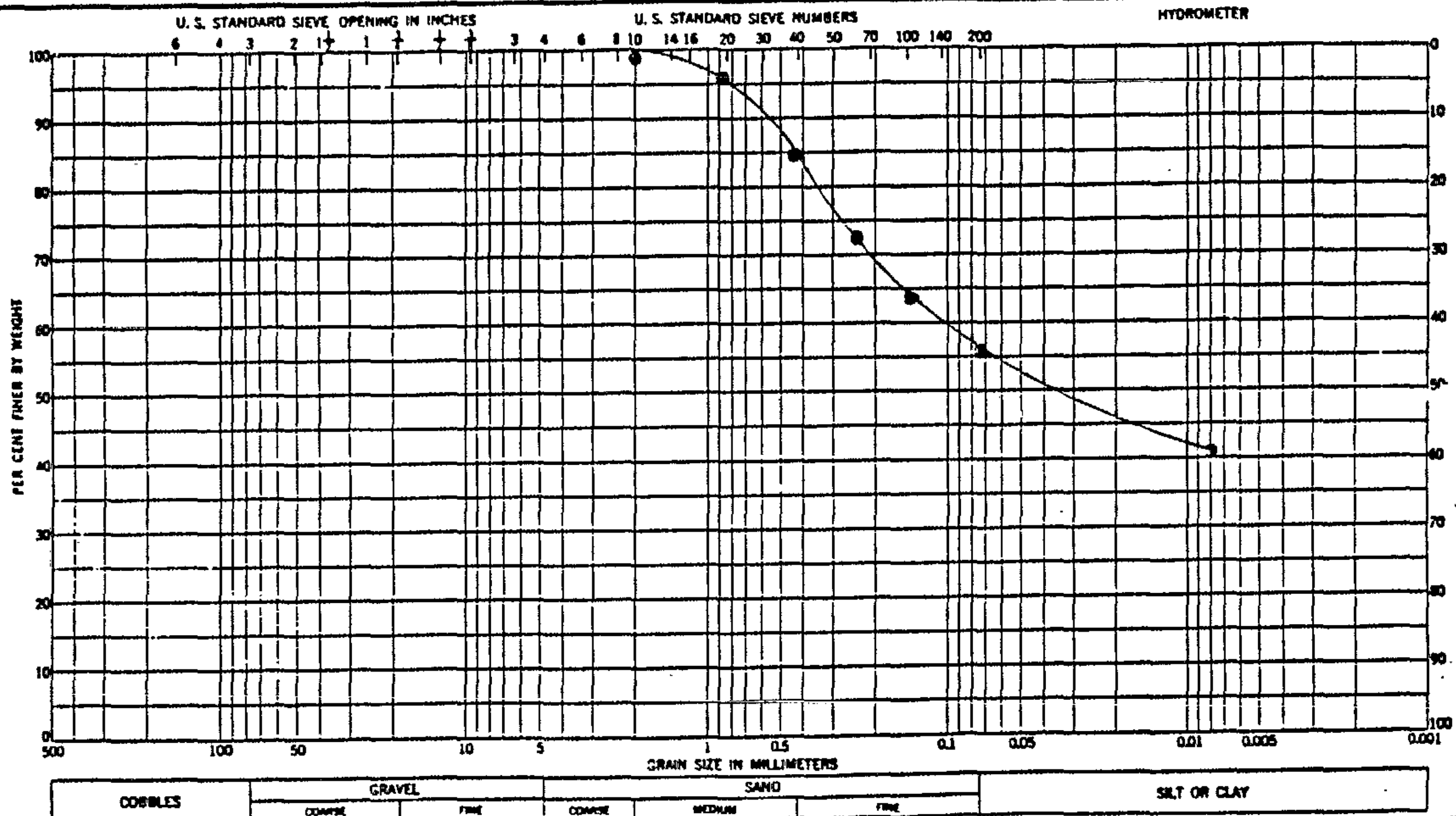
Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	19-24	CL				

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No	I
Date	December, 1985

GRADATION CURVES

100434

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	48-59	CL				

GRADATION CURVES

Project: Virginia Wood Preservers

Area: Henrico County, VA.

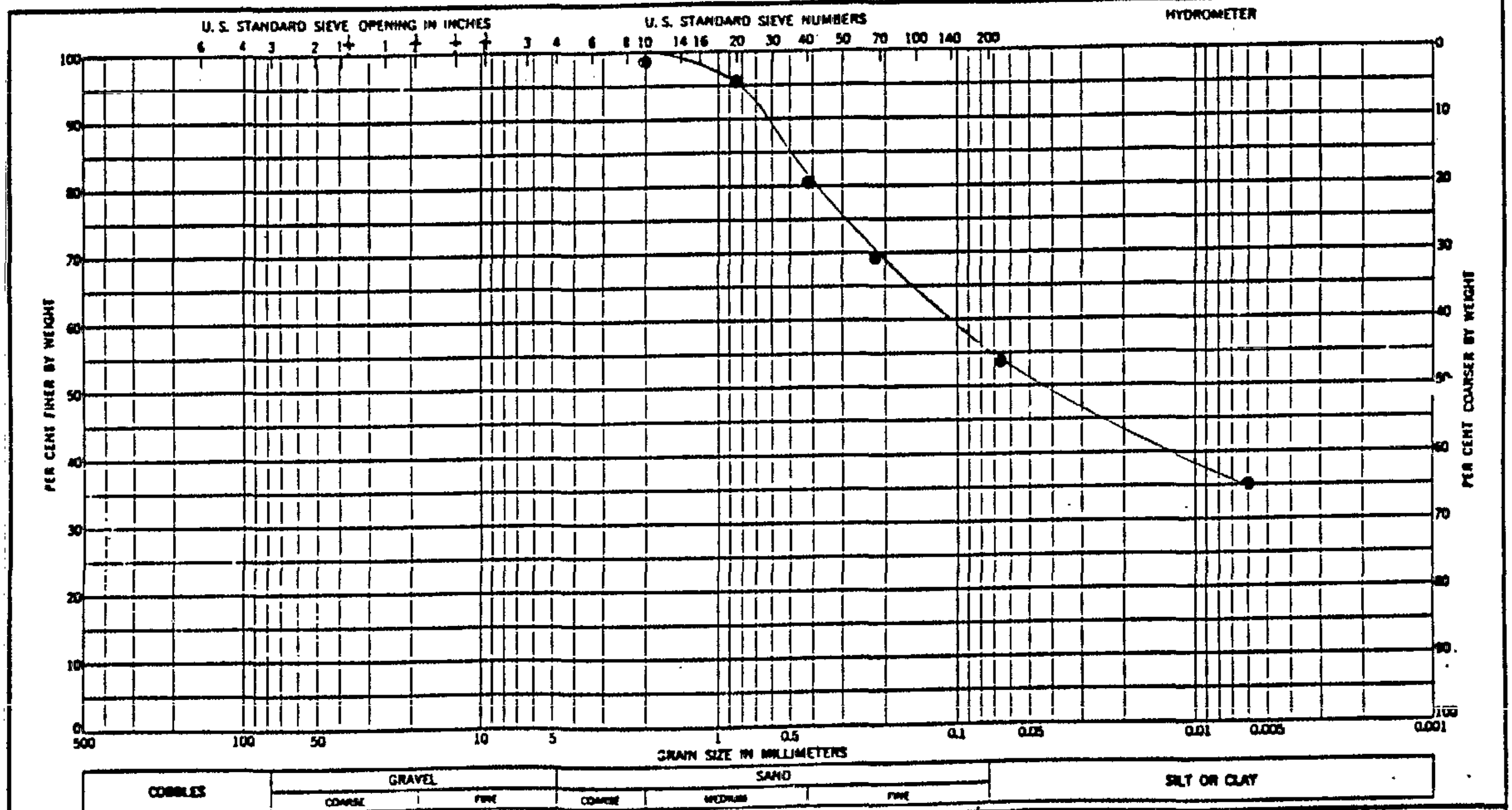
Boring No.: HS

Date: December, 1935

100435

ORIGINAL (Red)

GRAIN SIZE DISTRIBUTION GRAPH



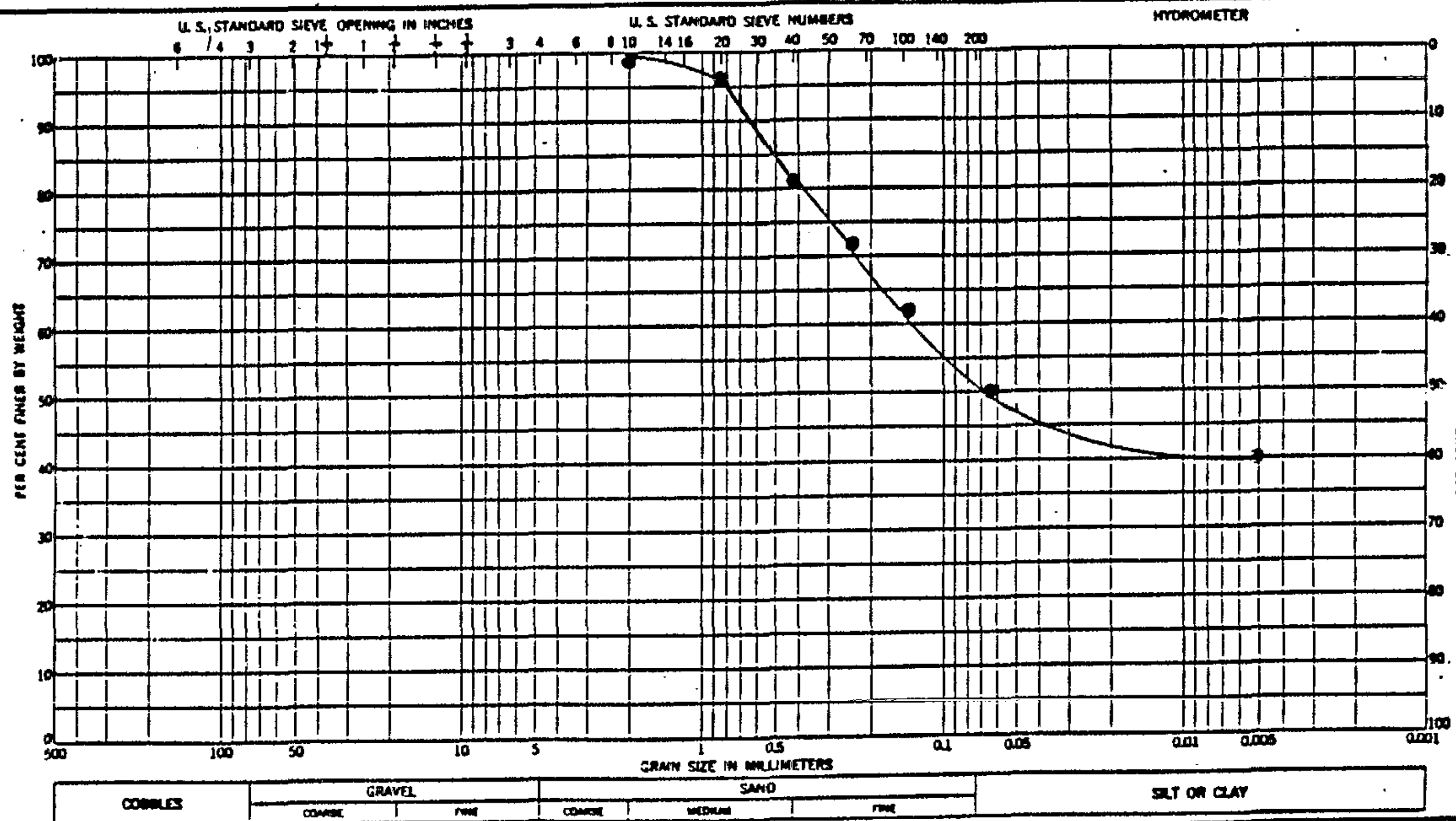
Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	52-57	ML				

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No	CS
Date	December, 1935

GRADATION CURVES

100436

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	18-24	CL				

Project Virginia Wood Preservers

Area Henrico County, VA.

Boring No. BS

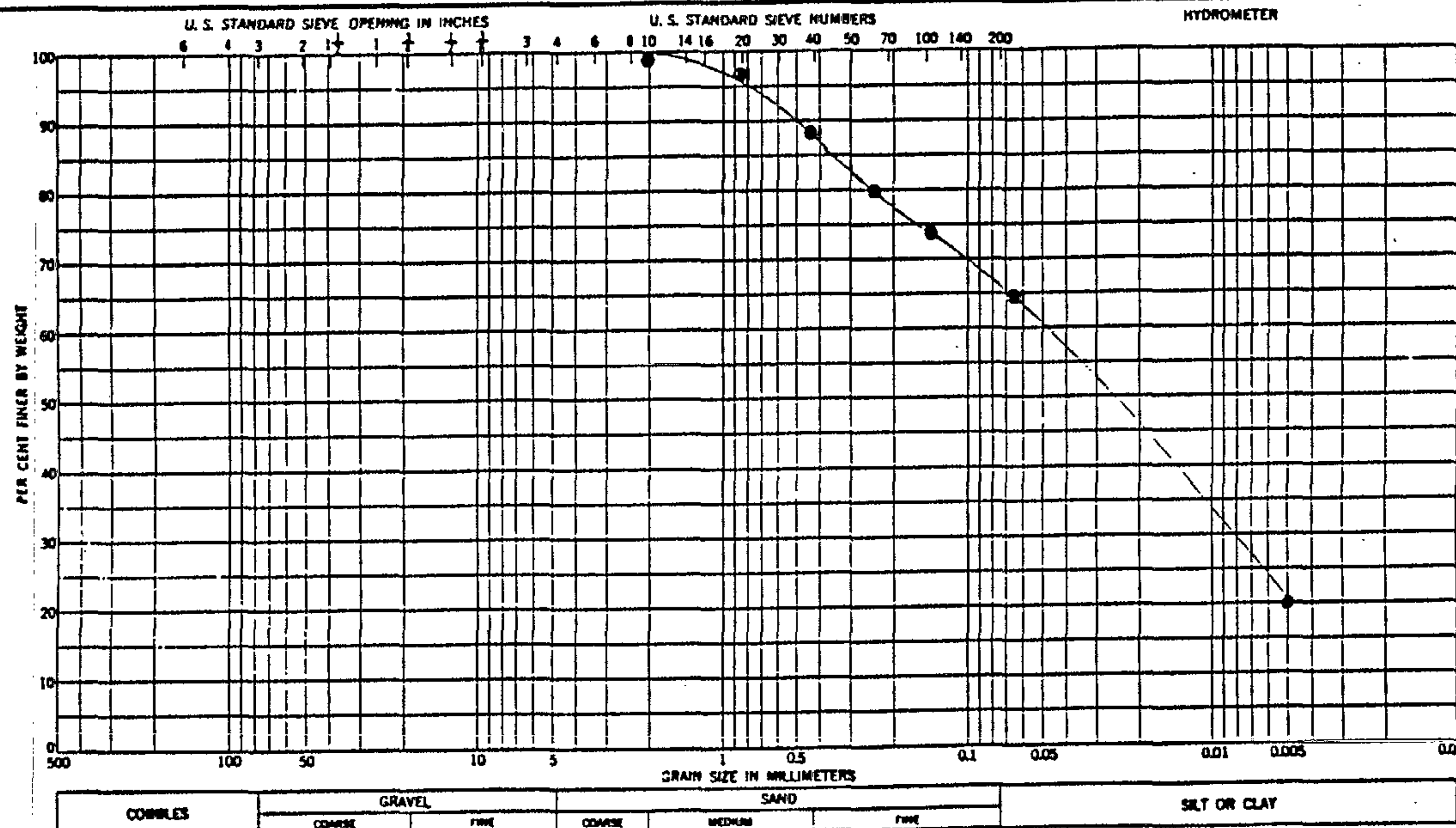
Date December, 1985

GRADATION CURVES

ORIGINAL

100437

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	19-20.6	CH				

GRADATION CURVES

Project: Virginia Wood Preservers

Area: Henrico County, VA.

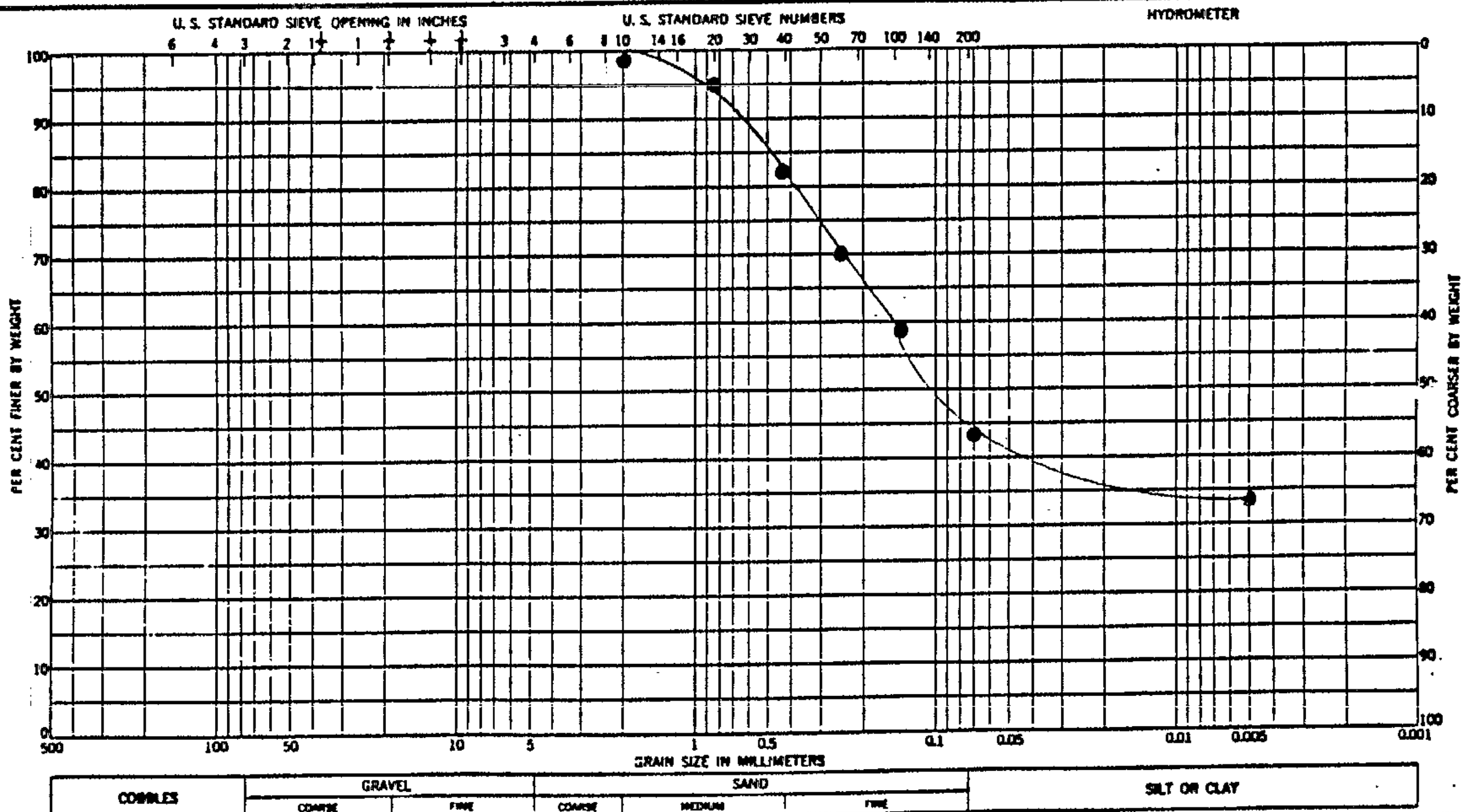
Boring No.: B-18

Date: December, 1985

ORIGINAL (Red)

100438

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	16-16.7	SC				

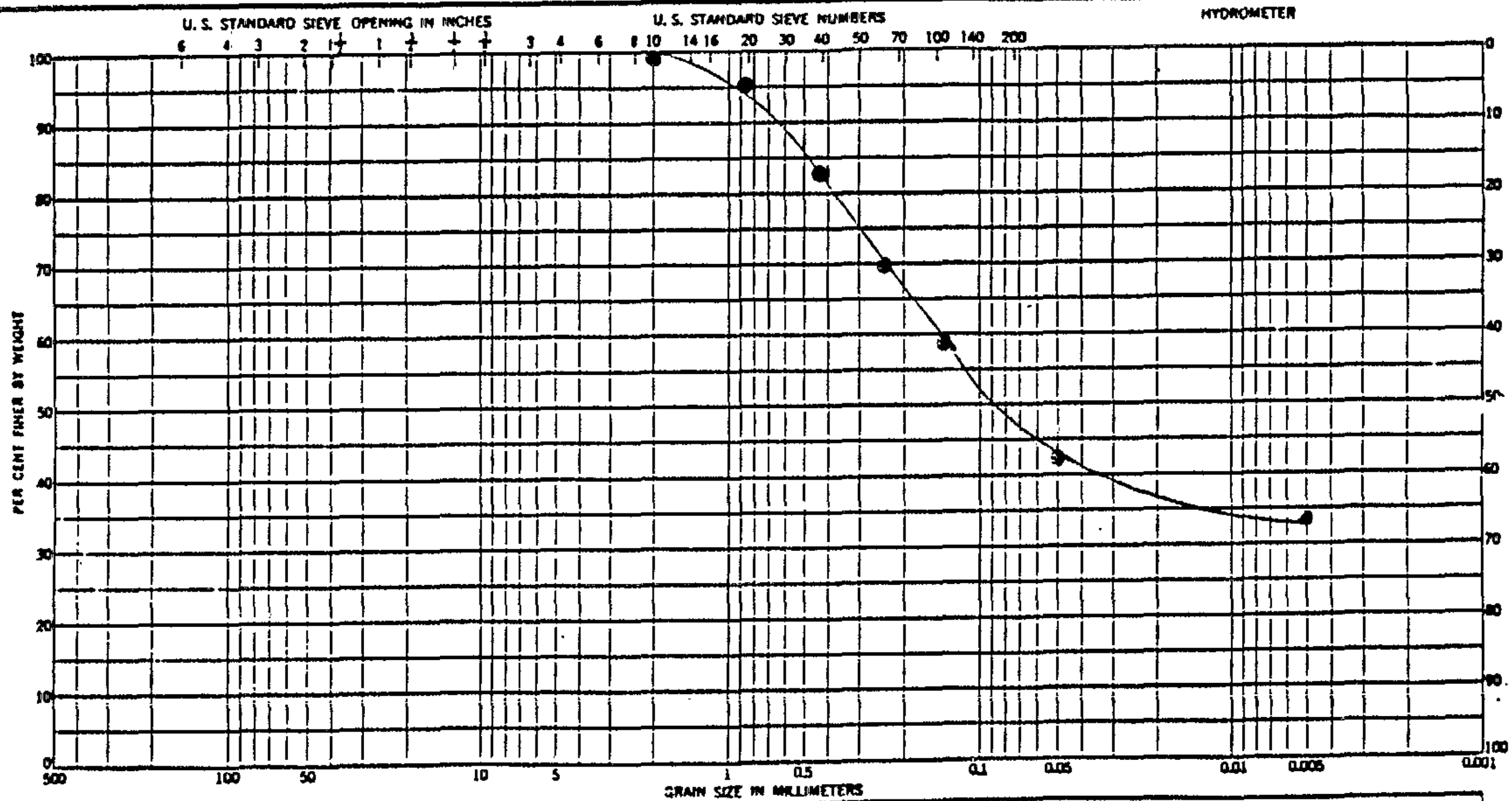
GRADATION CURVES

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No.	GMW-10
Date	December, 1985

ORIGINAL (Red)

100439

GRAIN SIZE DISTRIBUTION GRAPH



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	8.5-9.0	SC				

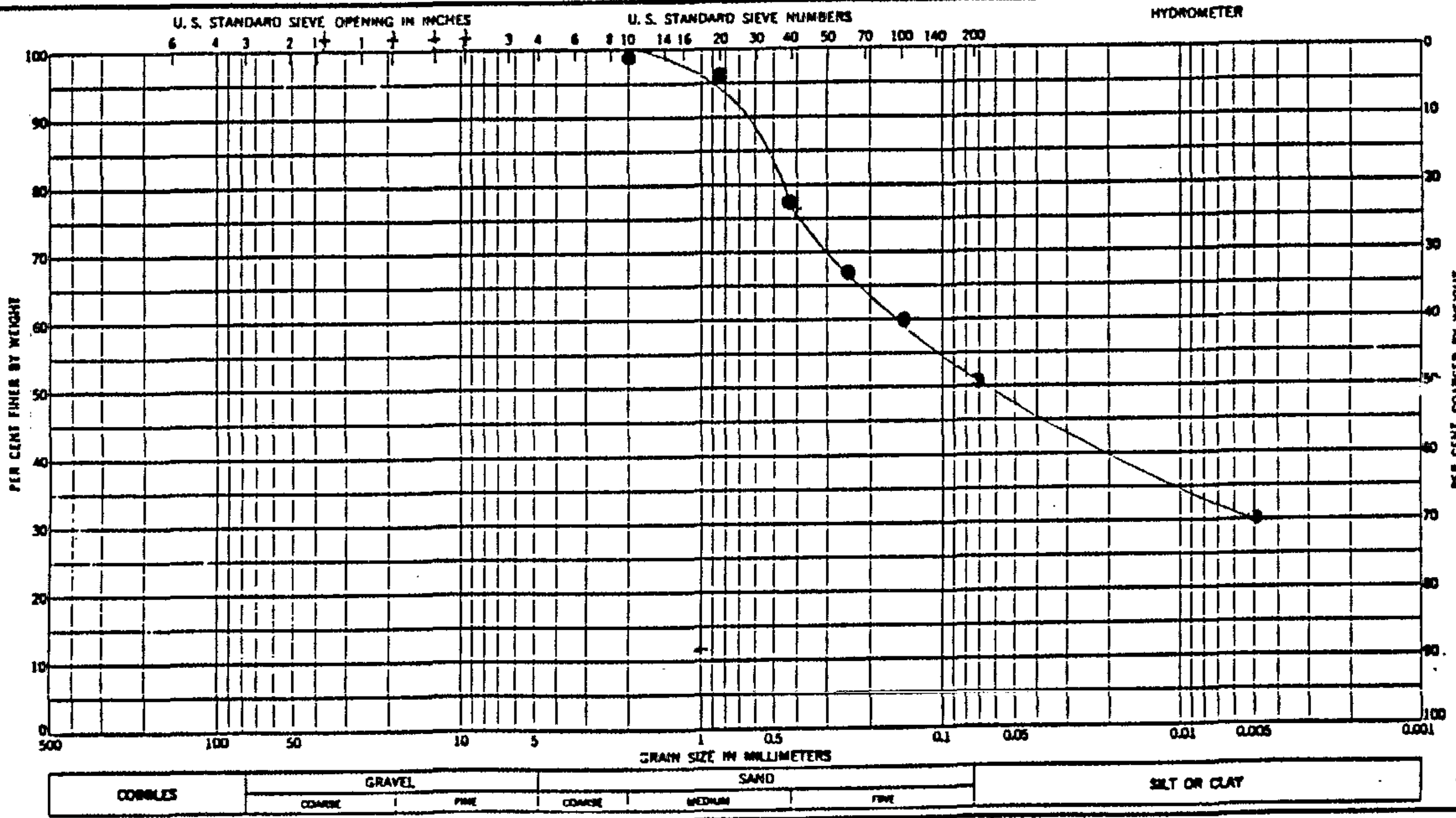
GRADATION CURVES

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No	GMW-10
Date	December. 1985

ORIGINAL (Red)

100440

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	12.5-13	ML				

Project: Virginia Wood Preservers

Area: Henrico County, VA.

Boring No. GMW-9

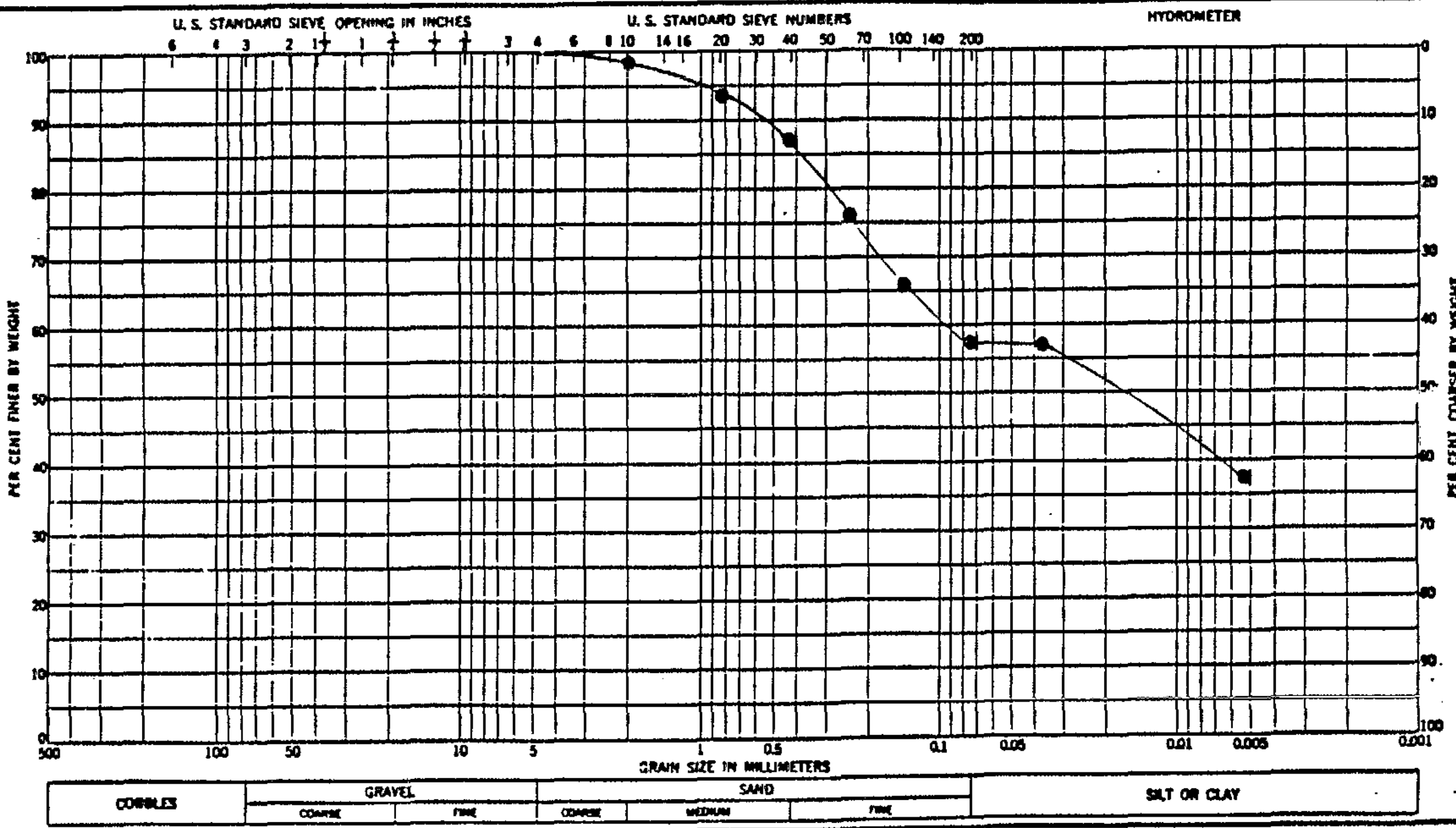
Date: December, 1985

GRADATION CURVES

100441

ORIGINAL (Red)

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	12-14	MH				

GRADATION CURVES

Project: Virginia Wood Preservers

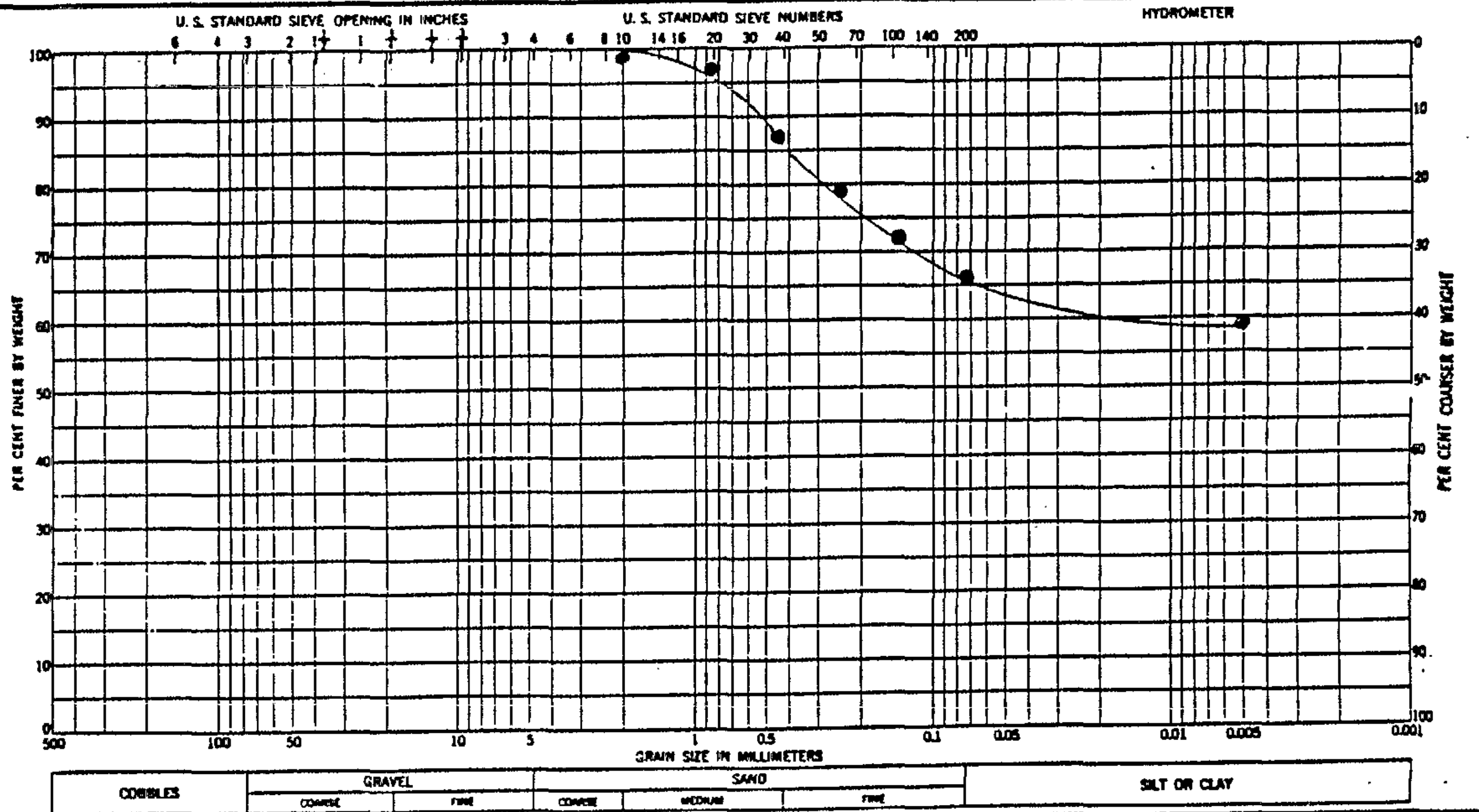
Area: Henrico County, VA.

Boring No. GMW-13

Date: December, 1985

100442

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	9.0-9.5	CL				

GRADATION CURVES

Project: Virginia Wood Preservers

Area: Henrico County, VA.

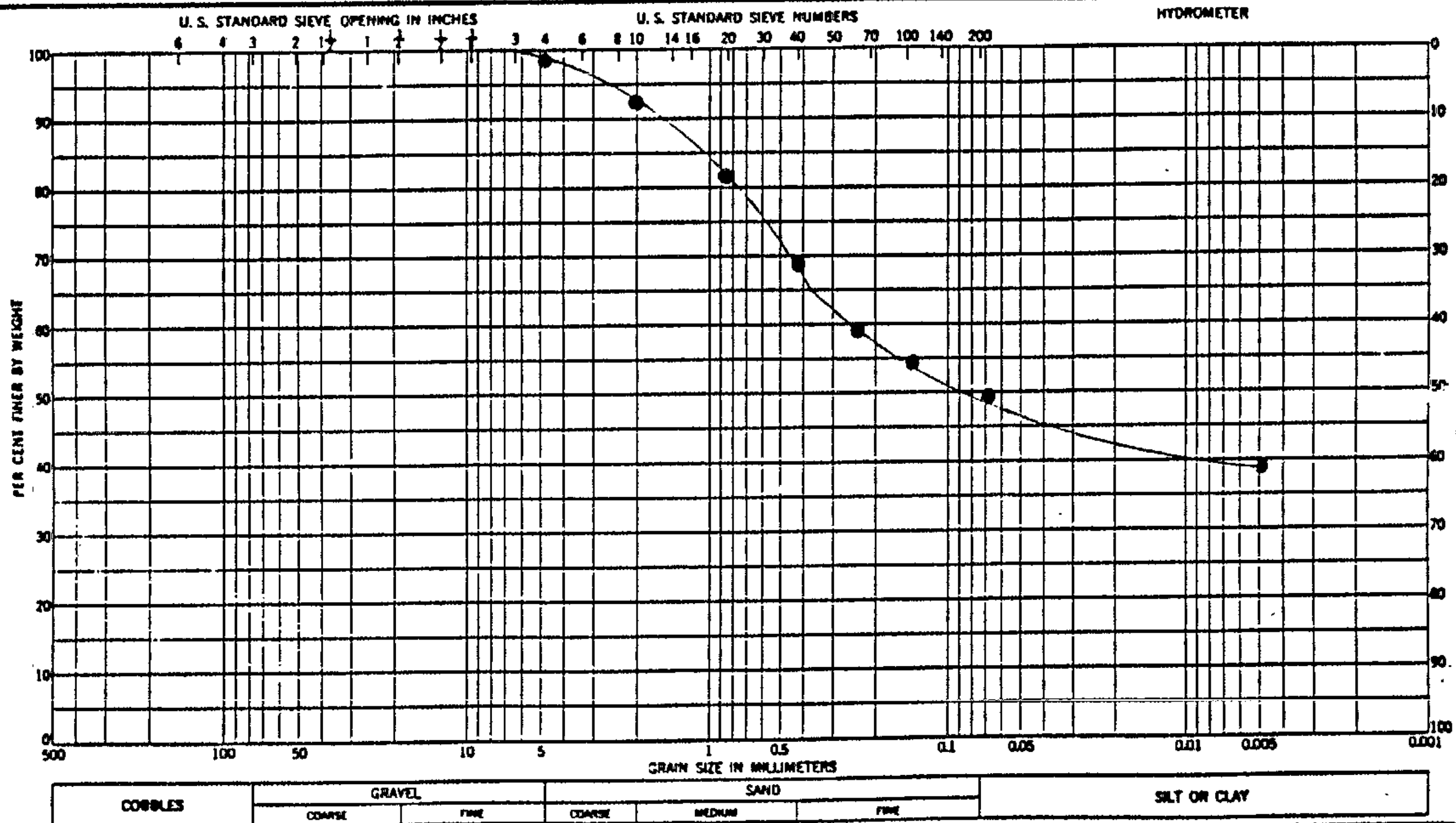
Boring No.: GMW-9

Date: December, 1995

ORIGINAL (Red)

100443

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	4.5-5.5	CL				

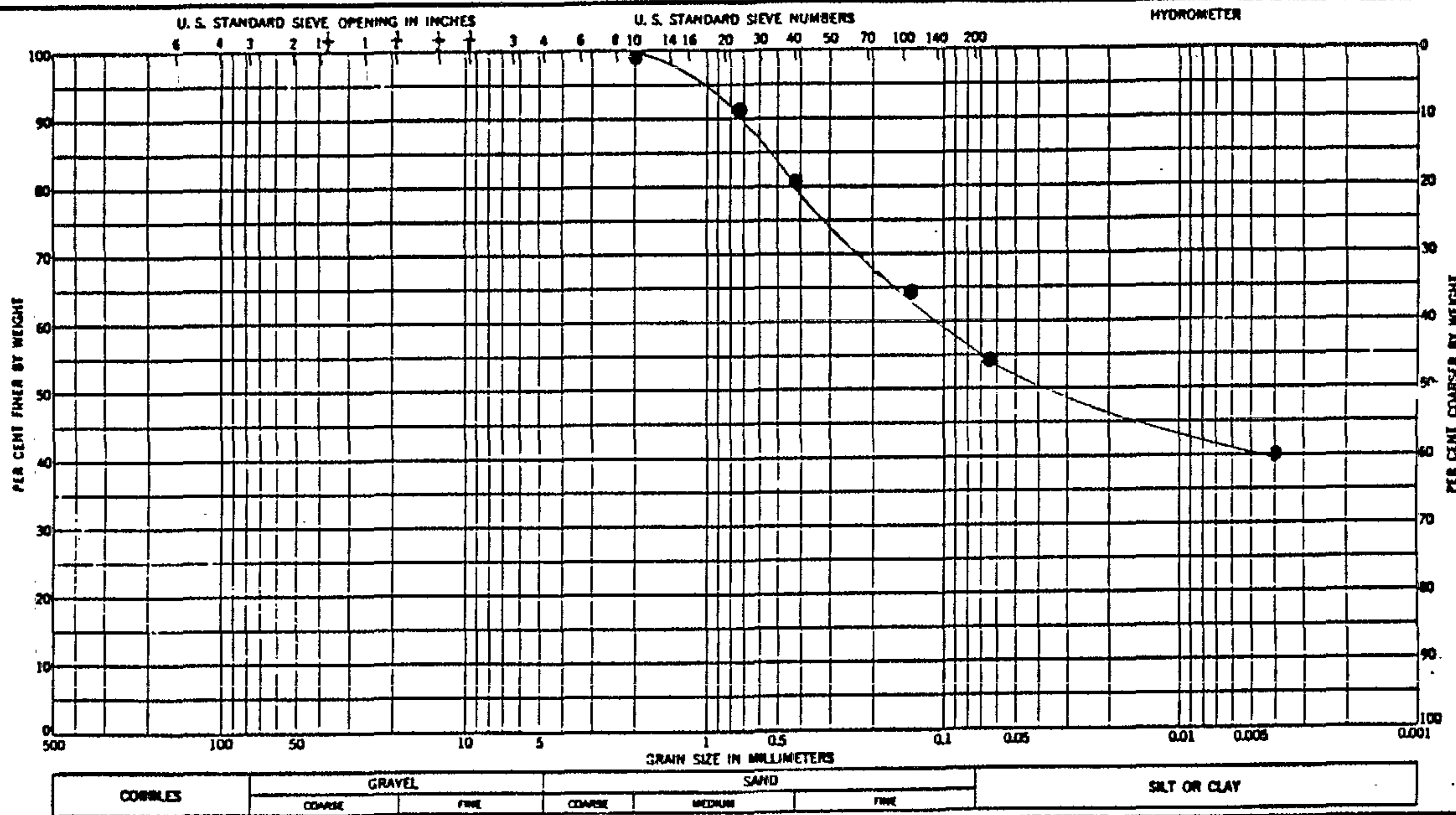
Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No.	GMW-3A
Date	December, 1985

GRADATION CURVES

ORIGINAL (Red)

100444

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	14-16	ML				

Project: Virginia Wood Preservers

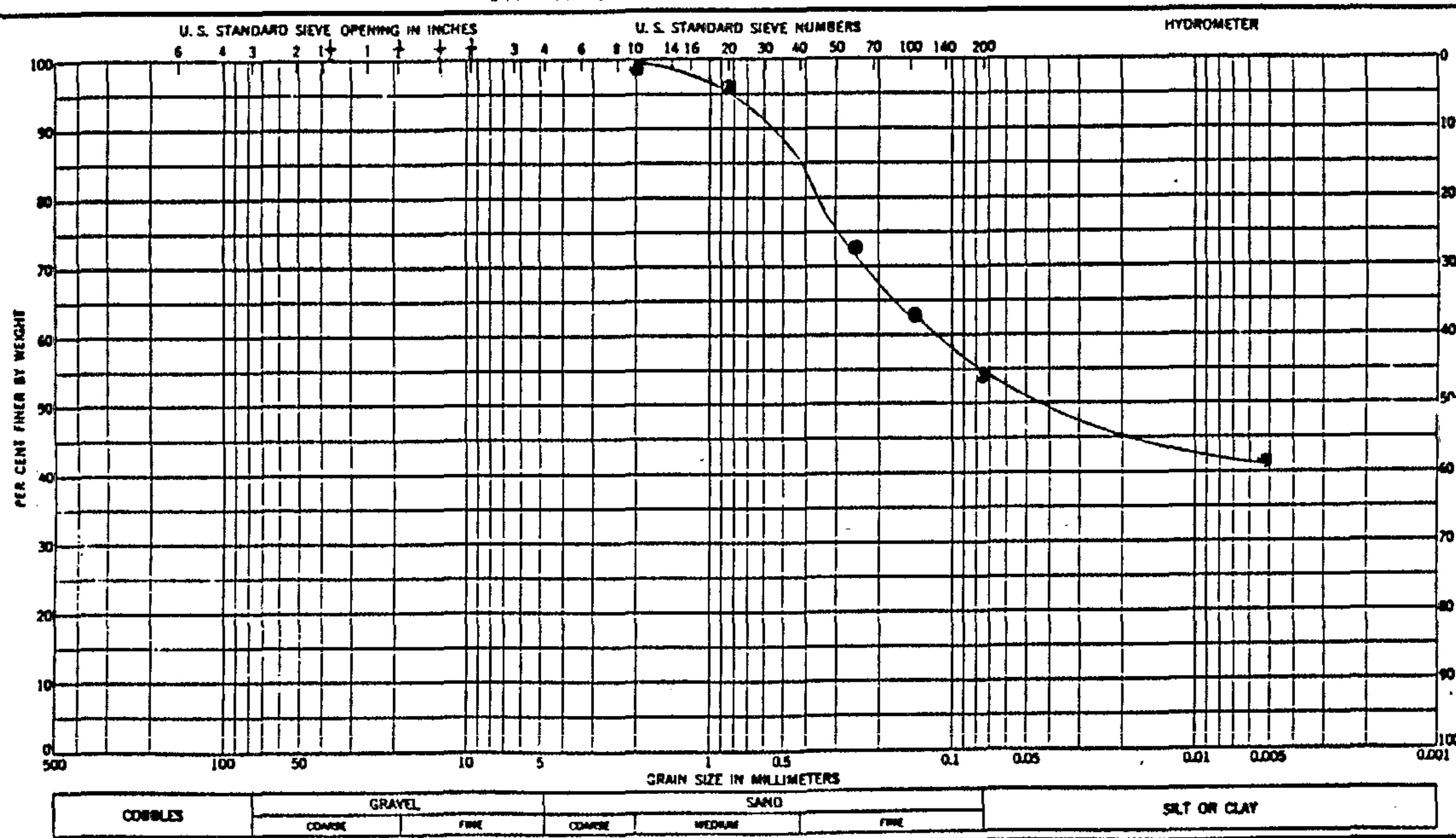
Area: Henrico County, VA.

Boring No. GMW-5

Date: December, 1985

GRADATION CURVES

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	6-8	CL				

GRADATION CURVES

Project: Virginia Wood Preservers

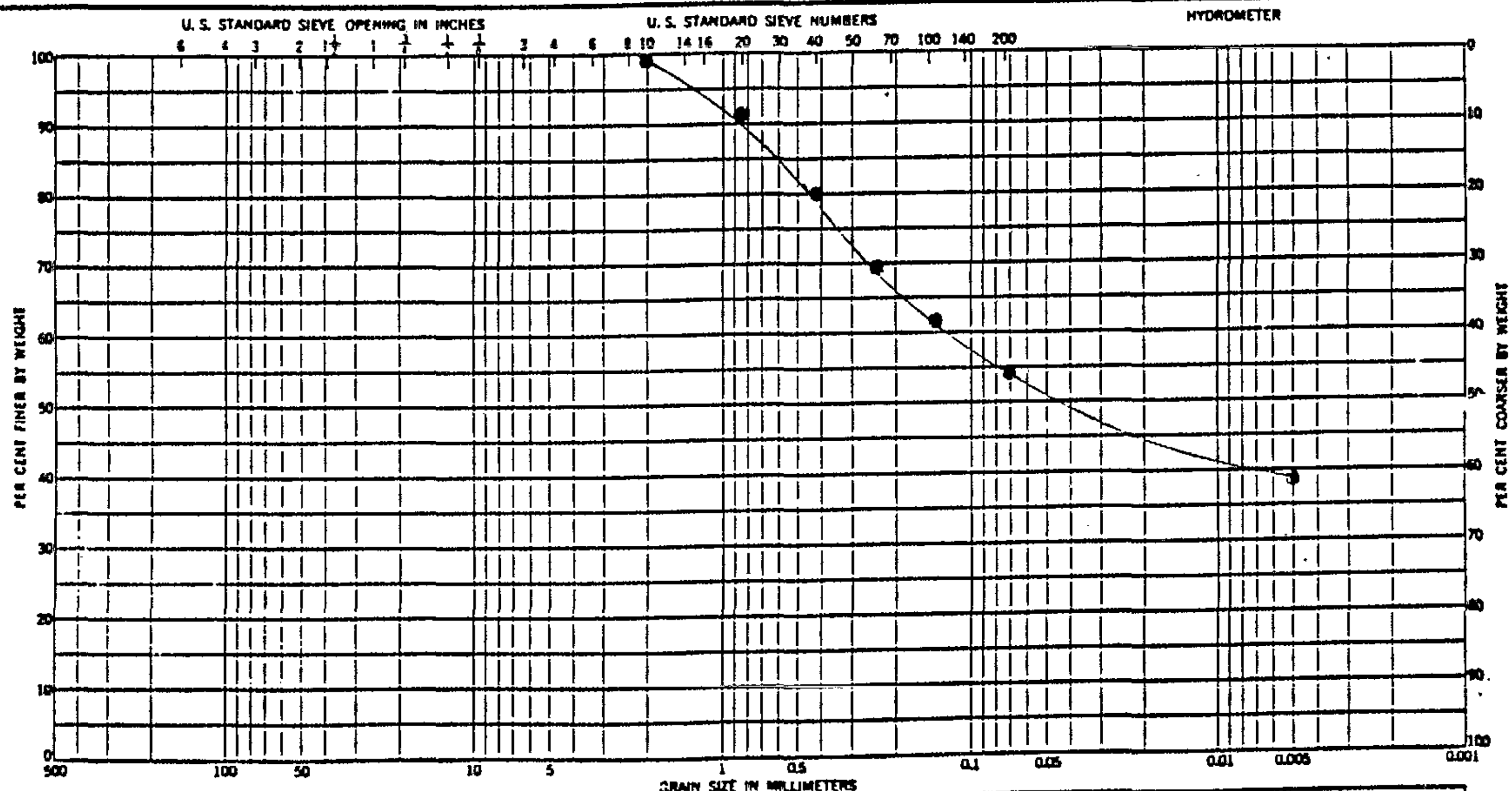
Area: Henrico County, VA.

Boring No. GMW-5

Date: December, 1985

100446

GRAIN SIZE DISTRIBUTION GRAPH



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	20-40	ML				

Project: Virginia Wood Preservers

Area: Henrico County, VA.

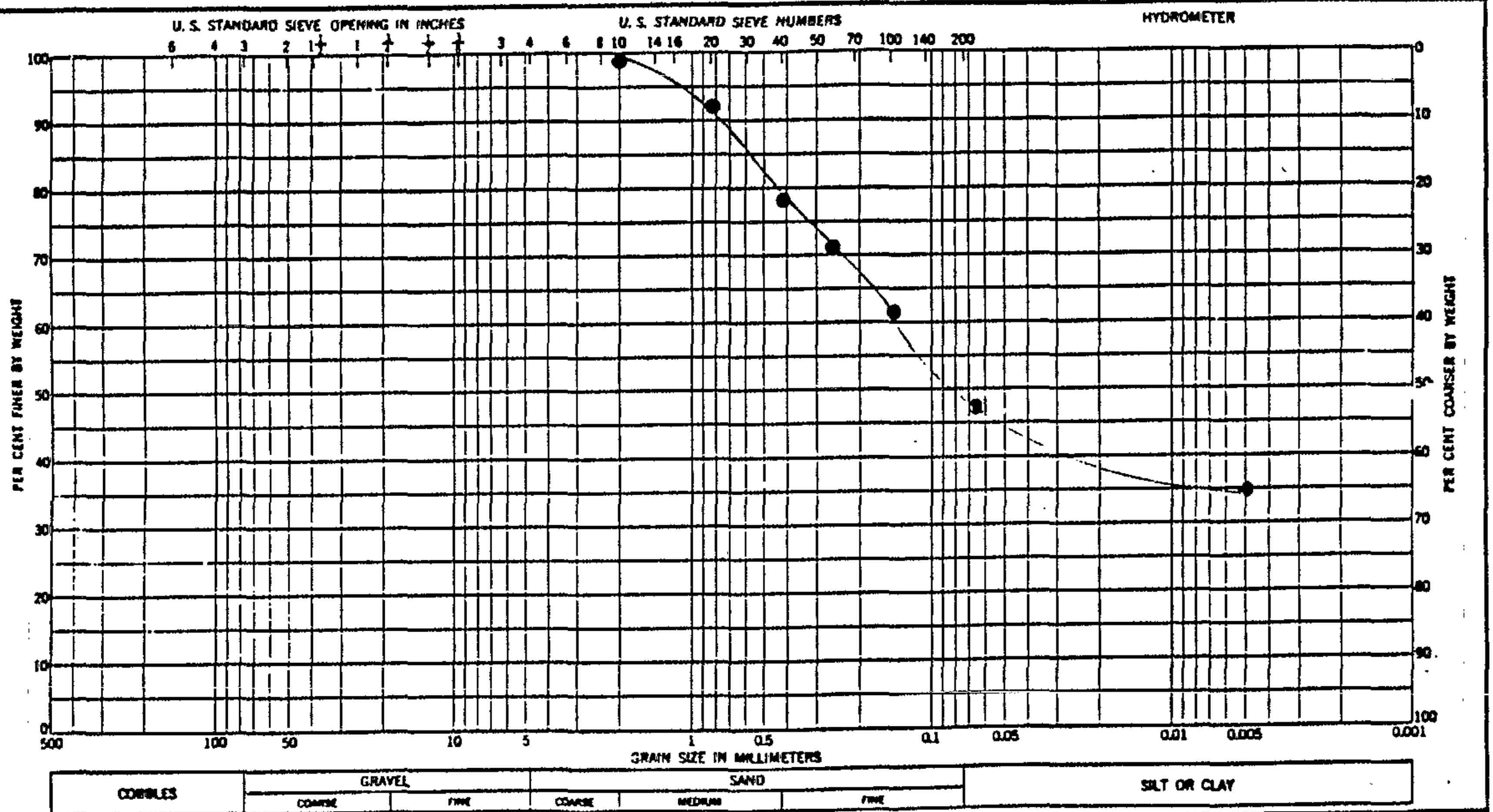
Boring No: GMW-4

Date: December, 1985

GRADATION CURVES

100447

GRAIN SIZE DISTRIBUTION GRAPH



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
	4.0-5.2	ML				

Project	Virginia Wood Preservers
Area	Henrico County, VA.
Boring No	GMW-4
Date	December, 1985

GRADATION CURVES

100448

ORIGINAL (Red)

APPENDIX THREE

INPUT AND OUTPUT FOR THE GROUND-WATER FLOW-MODEL

ORIGINAL (Red)

DESCRIPTION OF GROUND-WATER FLOW MODEL OUTPUT

The groundwater flow conditions at the Virginia Wood Preserving site were modeled using the U. S. Geological Survey modular three dimensional finite-difference computer ground water model (McDonald and Harbaugh, 1984). All values are in units of feet (length) and seconds (time). For the Virginia Wood Preservers site four layers are simulated, an upper unconfined layer, a low permeability aquitard, a lower confined layer, and an impermeable base layer. North Run Creek is simulated through nodal designation, and assignment of appropriate stream bed conductivity, elevation, and water levels. Solution is by the Strongly Implicit Procedure (SIP).

Page 2 and 3 of the model output, shown in the following pages, gives the boundary conditions for the model area; 0 stands for an inactive node, 1 for an active variable head node, and -1 for an active constant head node. Pages 3 through 7 give the initial head values for layer 1 and 2, the anisotropy factor, which is set equal to 1.0 (homogeneous condtions), the dimensions of each cell (DELR and DELC, each set to 1.0), and the hydraulic conductivity of layer 1. The "bottom" matrix designates elevation of the bottom of layer 1. The next matrix given,, the vertical conductivity/thickness matrix, refers to the vertical conductivity of the hardpan, or friable clay unit, divided by its thickness. Transmissivity, and the number of time steps used (in this case 1) is described on page 11 as is the error criterion, and the input matrix for simulation of the river. Iteration parameters are shown on page 12. The final head matrices are given on pages 12 through

AR100450

16, and the volumetric budget for the model is given on page 16 and 17. The volumetric budget gives the total discharge from the system, and the total discharge into the system. Because the model simulation is steady-state, the difference between discharge in and out of the modeled area can be used as a rough check on how well the model is performed. In this case the difference is 1.8 cubic feet per day.

Values Of 1000. in the final head matrix refer to no-flow nodes, and vales of 1E+30 refer to nodes that were (unsaturated conditions in the shallow perched water table. The total time increment of the model is 86,400 seconds (24 hours).

```
                 U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL

      THREE DIMENSIONAL FLOW MODEL FOR THE VIRGINIA WOOD PRESERVERS SITE, RICHMOND, VIRGINIA

   2 LAYERS        25 ROWS        25 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS SECONDS
I/O UNITS:
ELEMENT OF IUNIT:  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
        I/O UNIT: 11  0  0 12  0  0  0  0 13  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 12/08/83 INPUT READ FROM UNIT  1
START HEAD WILL BE SAVED
 13183 ELEMENTS IN X ARRAY ARE USED BY BAS
 13183 ELEMENTS OF X ARRAY USED OUT OF  30000
BCF1 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 1, 12/08/83 INPUT READ FROM UNIT 11
STEADY-STATE SIMULATION
     LAYER  AQUIFER TYPE
     ------------------
        1         1
        2         0
  1252 ELEMENTS IN X ARRAY ARE USED BY BCF
 14435 ELEMENTS OF X ARRAY USED OUT OF  30000
RIV1 -- RIVER PACKAGE, VERSION 1,  12/08/83 INPUT READ FROM UNIT 12
MAXIMUM OF   27 RIVER NODES
   162 ELEMENTS IN X ARRAY ARE USED FOR RIVERS
 14597 ELEMENTS OF X ARRAY USED OUT OF  30000
SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE, VERSION 1, 12/08/83 INPUT READ FROM UNIT 13
MAXIMUM OF 100 ITERATIONS ALLOWED FOR CLOSURE
 5 ITERATION PARAMETERS
  5405 ELEMENTS IN X ARRAY ARE USED BY SIP
 20002 ELEMENTS OF X ARRAY USED OUT OF  30000
THREE DIMENSIONAL FLOW MODEL FOR THE VIRGINIA WOOD PRESERVERS SITE, RICHMOND, VIRGINIA
```

ORIGINAL
(Red)

100452

ORIGINAL (Red)

BOUNDARY ARRAY FOR LAYER 1 WILL BE READ ON UNIT 1 USING FORMAT: (25I2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	-1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
18	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
19	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
20	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
21	-1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
22	-1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-1	1	1	1	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-1	1	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

BOUNDARY ARRAY FOR LAYER 2 WILL BE READ ON UNIT 1 USING FORMAT: (25I2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1

3	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	-1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
18	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
19	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
20	-1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0
21	-1	1	1	1	1	1	1	1	1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
22	-1	1	1	1	1	1	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	-1	1	1	1	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	-1	1	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

AQUIFER HEAD WILL BE SET TO 999.99 AT ALL NO-FLOW NODES (IBOUND=0).

INITIAL HEAD FOR LAYER 1 WILL BE READ ON UNIT 1 USING FORMAT: (25F6.1)

	1 11 21	2 12 22	3 13 23	4 14 24	5 15 25	6 16	7 17	8 18	9 19	10 20
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	195.6	193.5	192.8	192.0
	191.3	190.5	190.1	189.4	188.8					
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	196.5	194.5	193.2	192.8	192.1
	191.6	191.0	190.3	189.5	188.7					
3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	197.5	195.5	194.4	194.0	193.7	193.3
	192.8	192.1	191.6	190.8	189.6					

ORIGINAL (Red)

100454

4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	198.3	196.4	195.3	195.3	195.0	194.6	194.2
	193.6	192.9	192.3	191.7	190.8					
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	202.8	201.2	199.0	196.7	196.4	196.3	196.1	195.7	195.4	194.9
	194.4	193.8	193.0	192.4	191.6					
6	209.2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	201.4	199.1	196.8	197.1	197.5	197.5	197.2	196.8	196.1	195.6
	195.2	194.6	193.8	193.1	192.3					
7	207.8	207.0	206.6	206.1	205.5	205.0	204.3	203.3	202.1	201.1
	199.0	197.6	198.7	199.8	200.3	200.0	199.3	198.4	197.2	196.3
	195.6	195.2	194.5	193.8	193.2					
8	207.9	206.5	205.6	204.5	203.5	202.7	201.8	200.9	200.0	199.1
	198.3	199.2	201.0	202.2	202.6	202.4	201.5	200.0	198.5	197.2
	196.3	195.6	195.1	193.8	192.9					
9	208.5	206.8	205.9	204.6	203.4	202.5	201.6	200.7	199.4	198.8
	199.0	200.8	202.5	203.8	204.4	204.1	202.9	201.8	200.0	198.4
	197.0	196.2	195.6	194.9	194.3					
10	209.4	207.7	206.5	205.4	204.0	203.0	202.2	201.4	200.6	200.0
	200.7	202.4	203.8	205.4	205.8	205.7	204.2	202.7	200.8	199.5
	198.1	197.8	196.0	195.4	194.7					
11	210.5	208.7	207.0	206.2	204.9	203.8	203.2	202.4	201.6	201.2
	202.5	203.5	204.6	206.8	207.6	207.7	205.2	203.4	201.5	200.4
	199.2	198.0	196.8	195.9	195.2					
12	211.5	210.1	208.2	206.9	205.9	204.8	204.1	203.6	203.3	203.2
	203.6	204.2	205.3	207.4	207.6	207.6	206.5	204.0	202.1	201.4
	200.4	199.2	197.8	199.6	195.8					
13	212.5	211.4	209.6	208.0	206.8	206.0	205.1	204.9	205.1	204.5
	205.0	205.3	205.4	207.0	207.6	207.6	207.6	204.2	203.4	202.9
	201.6	200.4	199.0	197.8	196.6					
14	213.8	212.5	211.1	209.6	208.2	207.0	206.2	206.0	206.1	205.8
	205.4	205.4	205.4	206.7	207.5	207.6	207.2	206.1	205.3	204.0
	202.9	201.5	200.1	199.0	197.8					
15	215.3	214.0	212.5	211.1	210.0	208.8	207.8	207.1	207.0	206.8
	206.0	205.4	205.6	206.6	207.4	207.4	207.6	207.6	207.5	205.0
	204.8	202.8	201.3	200.0	198.9					
16	216.7	215.4	214.2	212.8	211.5	210.5	209.8	209.0	209.0	208.8
	208.4	207.7	207.2	207.3	207.6	207.6	207.7	207.7	207.7	206.2
	204.8	203.6	202.3	200.8	200.0					
17	217.9	216.8	215.6	214.5	213.2	212.3	211.5	210.9	210.4	210.0
	210.0	209.8	209.1	207.9	207.6	207.7	207.8	207.7	207.7	206.6
	205.5	204.4	203.2	201.7	0.0000E+00					
18	219.5	218.2	217.0	216.0	215.0	214.0	213.5	212.8	212.2	211.8

ORIGINAL (Red)

100455

	211.3	210.8	209.6	208.3	207.8	207.8	207.9	207.8	207.4	206.4
	205.8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
19	221.0	219.8	218.5	217.5	216.6	215.8	215.4	214.8	214.1	213.6
	213.0	212.3	211.2	209.5	209.0	209.0	208.5	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
20	222.5	221.5	220.2	219.0	218.3	217.6	216.9	216.3	215.7	215.2
	214.5	213.5	212.5	211.1	209.8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
21	223.5	222.9	222.1	221.0	220.2	219.5	218.9	218.0	217.3	216.5
	215.7	214.6	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
22	224.3	223.7	223.3	222.8	221.9	221.1	220.2	219.5	218.6	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
23	224.7	224.4	223.9	223.5	223.2	222.3	221.4	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
24	225.0	224.7	224.4	224.1	223.7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
25	225.2	225.1	224.8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					

INITIAL HEAD FOR LAYER 2 WILL BE READ ON UNIT 1 USING FORMAT: (25F6.1)

	1 11 21	2 12 22	3 13 23	4 14 24	5 15 25	6 16	7 17	8 18	9 19	10 20
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	195.3	194.0	193.0	192.5
	192.0	191.5	191.0	190.5	190.0					
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	194.0	193.5	193.2	193.2
	192.8	191.8	191.5	190.7	189.8					
3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	197.7	196.0	194.8	194.8	194.6	194.5
	194.0	193.6	193.1	192.0	190.8					
4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

ORIGINAL (Red)

100456

	0.0000E+00	0.0000E+00	0.0000E+00	198.6	197.0	196.2	196.1	195.9	195.7	195.5
	195.2	194.7	194.0	193.0	191.8					
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	200.2	199.0	197.9	197.9	198.0	197.9	197.5	197.0	196.5
	195.9	195.5	195.0	194.0	193.0					
6	205.6	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	200.2	199.2	198.8	199.2	199.5	199.6	199.5	199.1	198.8	198.1
	197.3	196.6	195.9	195.1	194.0					
7	205.1	204.3	203.9	203.3	202.9	202.4	202.0	201.5	200.9	200.3
	199.6	199.5	200.1	200.5	200.8	200.8	200.4	200.0	199.7	199.3
	198.9	198.0	197.0	196.0	195.0					
8	205.0	204.0	203.0	202.4	201.8	201.6	201.2	200.8	200.3	199.8
	200.2	200.8	201.4	202.0	202.0	201.9	201.8	201.4	200.9	200.3
	199.8	199.4	198.6	197.4	196.5					
9	205.3	204.5	203.6	202.9	202.1	201.7	201.3	201.0	200.9	200.8
	201.4	202.2	202.9	203.2	203.2	203.1	202.8	202.4	202.0	201.3
	200.8	200.2	199.6	199.0	197.7					
10	205.9	205.2	204.4	203.7	203.1	202.6	202.2	202.1	202.1	202.2
	202.5	203.1	203.8	204.0	204.0	203.8	203.6	203.4	203.0	202.5
	201.9	201.3	200.7	199.9	199.2					
11	206.3	205.8	205.1	204.6	204.0	203.5	203.2	203.0	203.0	203.1
	203.4	204.0	204.5	204.7	204.9	204.8	204.5	204.2	203.8	203.4
	202.9	202.2	201.6	201.0	200.5					
12	206.8	206.3	205.8	205.2	204.7	204.4	204.2	204.0	204.0	204.0
	204.2	204.8	205.2	205.4	205.4	205.4	205.4	205.1	204.7	204.2
	203.8	203.2	202.6	201.8	201.2					
13	207.5	206.9	206.4	205.9	205.5	205.1	204.9	204.8	204.8	204.9
	205.0	205.2	205.3	205.5	205.5	205.6	205.6	205.6	205.4	205.0
	204.5	204.0	203.5	202.8	202.1					
14	207.9	207.5	207.0	206.5	206.1	205.8	205.7	205.5	205.4	205.5
	205.5	205.6	205.6	205.8	205.8	205.8	205.9	205.9	205.8	205.6
	205.3	204.9	204.1	203.7	203.0					
15	208.8	208.2	207.8	207.2	206.8	206.5	206.3	206.1	206.1	206.0
	206.0	206.0	206.2	206.5	207.0	207.1	207.2	207.2	206.7	205.9
	205.5	205.4	205.0	204.3	203.6					
16	209.8	209.2	208.8	208.1	207.6	207.1	206.8	206.7	206.7	206.8
	206.9	207.1	207.3	207.4	207.5	207.4	207.4	207.4	207.0	206.3
	205.8	205.6	205.5	205.0	204.2					
17	210.6	210.0	209.6	209.1	208.6	208.1	207.8	207.6	207.5	207.7
	207.9	208.1	208.2	208.0	207.9	207.7	207.7	207.6	207.1	206.3
	205.8	205.6	205.4	205.2	0.0000E+00					
18	211.5	210.9	210.5	209.9	209.5	209.2	208.9	208.9	208.8	208.8
	208.8	208.8	208.7	208.6	208.5	208.2	207.9	207.6	207.1	206.4

INITIAL (Red)

100457

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      205.8    0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 19   212.5    211.8      211.3      210.9      210.5      210.2      210.0      209.9      209.2      209.8
      209.8    209.7      209.5      209.2      208.9      208.6      208.4      0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 20   213.2    212.6      212.2      211.7      211.4      211.2      210.9      210.8      210.6      210.4
      210.3    210.2      209.9      209.5      209.1      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 21   214.2    213.7      213.1      212.7      212.4      212.0      211.7      211.4      211.2      210.8
      210.6    210.4      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 22   215.1    214.6      214.0      213.6      213.2      212.8      212.4      211.8      211.5      0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 23   216.0    215.4      215.0      214.5      213.9      213.4      212.8      0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 24   216.6    216.0      215.6      215.2      214.7      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
 25   217.2    216.6      216.0      0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
     0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
DEFAULT OUTPUT CONTROL -- THE FOLLOWING OUTPUT COMES AT THE END OF EACH STRESS PERIOD:
TOTAL VOLUMETRIC BUDGET
          HEAD
          DRAWDOWN

                                   COLUMN TO ROW ANISOTROPY =   1.000000
                                                       DELR =   100.0000
                                                       DELC =   100.0000
                                     HYD. COND. ALONG ROWS =   0.9100000E-05 FOR LAYER  1


                              BOTTOM FOR LAYER  1 WILL BE READ ON UNIT 11 USING FORMAT: (25F6.1)
                       ------------------------------------------------------------------------

          1      2      3      4      5      6      7      8      9     10     11     12     13     14     15
         16     17     18     19     20     21     22     23     24     25
 ...........................................................................................................
  1     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
  2     0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
        0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
```

100458

ORIGINAL
(Red)

3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	196.7	195.0	1000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
6	202.5	202.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	196.5	195.0	194.6	1000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
7	202.3	201.8	201.4	200.9	200.5	200.0	199.5	199.0	198.5	197.5	196.7	196.4	196.1	1000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
8	204.0	202.3	200.0	199.6	199.2	198.8	198.5	198.1	197.7	197.1	197.4	197.5	197.7	1000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
9	206.2	204.7	202.9	202.1	201.7	199.8	199.7	199.7	199.8	199.3	199.5	200.0	201.7	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
10	207.9	206.2	204.9	203.7	203.3	202.6	201.8	201.7	201.4	201.4	201.8	202.5	202.9	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
11	208.3	207.7	207.0	205.0	204.5	204.0	203.5	203.1	202.7	202.5	202.7	204.4	204.7	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
12	209.3	208.5	207.4	205.5	204.5	205.1	204.5	204.2	204.1	204.3	204.7	205.0	205.0	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
13	210.0	209.3	208.9	208.1	208.1	207.9	204.7	204.4	203.9	204.7	205.3	205.5	205.2	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
14	211.2	209.8	209.2	208.9	208.4	208.0	207.5	206.2	205.2	205.5	206.2	205.8	205.0	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
15	212.7	211.3	209.8	209.3	208.9	208.7	208.5	208.1	207.9	207.0	206.6	204.5	203.8	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
16	213.7	212.6	211.4	210.8	209.4	208.0	207.9	207.8	207.7	207.5	206.7	206.9	206.0	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
17	215.1	214.0	212.9	212.3	210.3	209.5	208.5	207.9	207.4	206.9	207.0	207.5	207.0	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
18	217.3	215.2	214.2	213.3	212.6	211.0	209.0	208.0	207.3	208.0	208.4	208.6	208.6	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
19	219.2	217.3	215.5	214.7	213.7	212.4	210.0	209.5	209.7	210.0	210.4	210.0	209.4	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
20	220.0	219.8	217.5	216.2	215.0	214.0	212.3	211.2	211.5	212.0	213.5	214.0	212.5	2000.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
21	220.7	220.6	220.2	219.0	217.4	215.8	214.5	213.7	213.9	213.5	213.0	212.5	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
22	220.8	220.7	220.4	220.2	219.2	217.3	216.2	215.5	214.5	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
23	220.9	220.8	220.6	220.5	220.5	218.7	217.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
24	221.0	220.9	220.8	220.8	221.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ORIGINAL (Red)

	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
25	221.2	221.1	221.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					

VERT HYD COND /THICKNESS FOR LAYER 1 WILL BE READ ON UNIT 11 USING FORMAT: (25F4.1)

	1 11 21	2 12 22	3 13 23	4 14 24	5 15 25	6 16	7 17	8 18	9 19	10 20
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	2.0000E-08	2.0000E-08	2.0000E-08	1.8000E-08	1.6000E-08	1.4000E-08	1.2000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	1.8000E-08	1.5000E-08	1.0000E-08	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
6	2.0000E-08	2.0000E-08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	2.0000E-08	2.0000E-08	1.8000E-08	1.5000E-08	1.0000E-08	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
7	1.2000E-08	1.0000E-08	1.0000E-08	1.0000E-08	1.0000E-08	1.0000E-08	1.0000E-08	1.0000E-08	1.0000E-08	1.0000E-08
	2.0000E-08	2.0000E-08	1.6000E-08	1.5000E-08	1.0000E-08	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
8	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08
	2.0000E-08	1.5000E-08	1.0000E-08	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
9	1.6000E-08	1.8000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08
	1.0000E-08	8.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
10	1.0000E-08	1.2000E-08	1.4000E-08	1.4000E-08	1.2000E-08	1.0000E-08	6.0000E-09	6.0000E-09	4.0000E-09	2.0000E-09
	4.0000E-09	6.0000E-09	7.0000E-09	8.0000E-09	7.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					

ORIGINAL (Red)

11	8.0000E-09	6.0000E-09	4.0000E-09	6.0000E-09	8.0000E-09	4.0000E-09	2.0000E-09	2.0000E-09	2.0000E-09	6.0000E-09
	6.0000E-09	6.0000E-09	6.0000E-09	4.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
12	4.0000E-09	3.0000E-09	1.0000E-09	3.0000E-09	3.0000E-09	2.0000E-09	1.5000E-09	1.5000E-09	2.0000E-09	4.0000E-09
	5.0000E-09	5.0000E-09	2.0000E-09	5.0000E-09	1.0000E-09	1.0000E-08	8.0000E-09	5.0000E-09	5.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
13	6.0000E-09	1.0000E-09	1.0000E-09	6.0000E-09	4.0000E-09	1.0000E-09	5.0000E-09	1.0000E-09	1.0000E-09	5.0000E-09
	5.0000E-09	1.0000E-09	7.0000E-09	5.0000E-09	1.0000E-09	1.2000E-08	1.5000E-08	1.0000E-08	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
14	1.0000E-09	5.0000E-10	1.0000E-09	4.0000E-09	3.0000E-09	2.0000E-10	1.0000E-09	2.0000E-09	4.0000E-09	5.0000E-09
	1.0000E-09	5.0000E-10	5.0000E-10	1.0000E-09	1.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	1.5000E-08	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
15	5.0000E-10	5.0000E-10	1.0000E-09	5.0000E-09	8.0000E-09	1.0000E-09	2.0000E-09	2.0000E-09	4.0000E-09	4.0000E-09
	1.0000E-09	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	1.0000E-08	1.0000E-08	2.0000E-08	1.0000E-08	1.0000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
16	5.0000E-10	5.0000E-10	5.0000E-10	1.0000E-09	5.0000E-09	5.0000E-09	5.0000E-09	4.0000E-09	1.0000E-09	5.0000E-10
	4.0000E-10	5.0000E-10	1.0000E-09	8.0000E-09	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	1.0000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
17	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10
	5.0000E-10	5.0000E-10	5.0000E-10	2.0000E-09	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	1.5000E-08
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
18	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10
	5.0000E-10	5.0000E-10	5.0000E-10	1.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	2.0000E-08	1.0000E-08	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
19	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10
	5.0000E-10	5.0000E-10	5.0000E-09	8.0000E-09	8.0000E-09	6.0000E-09	6.0000E-09	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
20	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
21	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	1.0000E-09	1.0000E-09	2.0000E-09	6.0000E-09	6.0000E-09
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
22	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
23	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	5.0000E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
24	5.0000E-10	5.0000E-10	5.0000E-10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00					
25	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

ORIGINAL (Red)

AR100461

```
       1       3      17    196.3       0.9000E-04       195.0        18
       1       2      17    195.8       0.9000E-04       194.3        19
       1       2      18    194.9       0.9000E-04       193.6        20
       1       1      19    194.1       0.9000E-04       192.8        21
       1       1      20    193.6       0.9000E-04       192.3        22
       1       1      21    193.1       0.9000E-04       191.9        23
       1       1      22    192.7       0.9000E-04       191.4        24
       1       1      23    192.2       0.9000E-04       190.9        25
       1       1      24    191.7       0.9000E-04       190.4        26
       1       1      24    191.2       0.9000E-04       189.9        27

AVERAGE SEED = 0.00279010
MINIMUM SEED = 0.00013895

  5 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:

       0.0000000E+00  0.7701708E+00  0.9471786E+00  0.9878601E+00  0.9972099E+00

  35 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1
MAXIMUM HEAD CHANGE FOR EACH ITERATION:
 HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL HEAD CHANGE LAYER,ROW,COL
 ------------------------------------------------------------------------------------------------------------------------------
 -4.108      (  1, 21, 10)  -2.771      (  1, 21,  4)  -2.384      (  1, 14, 16)  -5.601      (  1, 20, 15)  -2.921      (  2, 13, 14)
 -1.285      (  1, 15, 13) -0.4309      (  1, 18, 15)  -1.353      (  1, 20, 15) -0.5912      (  2, 16, 12)  -2.276      (  1, 20, 15)
 -0.6515     (  2,  4, 14) -0.2853      (  2, 14, 12) -0.3026      (  2, 14, 10) -0.4277      (  1, 20, 15) -0.2734      (  2,  9, 15)
 -0.3829     (  1, 17, 10) -0.1883      (  1, 19,  7) -0.1546      (  1, 20, 15) -0.7674E-01 (  1, 18,  8) -0.3876      (  1, 20, 15)
 -0.1136     (  2,  4, 14)  0.9248E-01 (  1, 18,  8) -0.8352E-01 (  1, 18,  7) -0.7338E-01 (  1, 20, 15) -0.5678E-01 (  1, 17,  9)
  0.9043E-01 (  1, 18,  7) -0.8930E-01 (  1, 19,  7) -0.6612E-01 (  1, 13,  9) -0.5205E-01 (  1, 13,  7)  0.1065      (  1, 13,  8)
 -0.3905     (  1, 17,  9)  0.7336E-01 (  1, 17,  8)  0.3923E-01 (  1, 17,  8) -0.1742E-01 (  1, 18,  8) -0.8096E-02 (  2,  9, 15)

                  HEAD IN LAYER  1 AT END OF TIME STEP  1 IN STRESS PERIOD  1
              ----------------------------------------------------------------

              1         2         3         4         5         6         7         8         9        10
             11        12        13        14        15        16        17        18        19        20
             21        22        23        24        25
 ...........................................................................................................
   1   1000.     1000.     1000.     1000.     1000.     1000.     1000.     1000.     1000.     1000.
       1000.     1000.     1000.     1000.     1000.     1000.     194.5     194.5     194.4     194.4
```

ORIGINAL (Red)

AR100462

0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

TRANSMIS. ALONG ROWS = 0.1400000E-04 FOR LAYER 2

SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE

MAXIMUM ITERATIONS ALLOWED FOR CLOSURE = 100
ACCELERATION PARAMETER = 1.0000
HEAD CHANGE CRITERION FOR CLOSURE = 0.10000E-01
SIP HEAD CHANGE PRINTOUT INTERVAL = 2
CALCULATE ITERATION PARAMETERS FROM MODEL CALCULATED WSEED
STRESS PERIOD NO. 1, LENGTH = 86400.00

NUMBER OF TIME STEPS = 1

MULTIPLIER FOR DELT = 1.000

INITIAL TIME STEP SIZE = 86400.00

27 RIVER REACHES

LAYER	ROW	COL	STAGE	CONDUCTANCE	BOTTOM ELEVATION	RIVER REACH
1	7	1	206.6	0.9000E-04	205.3	1
1	8	2	205.8	0.9000E-04	204.5	2
1	8	3	204.8	0.9000E-04	203.5	3
1	8	4	203.9	0.9000E-04	202.6	4
1	8	5	203.2	0.9000E-04	201.9	5
1	8	6	202.9	0.9000E-04	201.6	6
1	8	7	202.6	0.9000E-04	201.3	7
1	8	8	202.1	0.9000E-04	200.8	8
1	8	9	201.7	0.9000E-04	200.4	9
1	8	10	201.2	0.9000E-04	200.0	10
1	7	11	200.8	0.9000E-04	199.5	11
1	6	12	200.3	0.9000E-04	199.0	12
1	6	13	199.8	0.9000E-04	198.5	13
1	5	14	199.3	0.9000E-04	198.0	14
1	5	15	198.8	0.9000E-04	197.5	15
1	4	15	198.3	0.9000E-04	197.0	16
1	4	16	197.5	0.9000E-04	196.2	17

ORIGINAL (Red)

AR100463

	194.3	194.2	194.2	194.1	194.2					
2	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	194.5	194.5	194.5	194.4
	194.4	194.3	194.3	194.2	194.2					
3	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	194.7	194.7	194.6	194.6	194.5	194.5
	194.4	194.4	194.3	194.3	194.3					
4	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1.0000E+30	194.8	194.7	194.7	194.6	194.6	194.5
	194.5	194.4	194.4	194.4	194.4					
5	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	199.6	199.2	1.0000E+30	194.8	194.7	194.7	194.6	194.6	194.6
	194.5	194.5	194.5	194.5	194.4					
6	209.2	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	200.2	199.9	199.5	1.0000E+30	194.8	194.7	194.7	194.7	194.6	194.6
	194.6	194.5	194.5	194.5	194.5					
7	206.5	205.7	205.0	204.3	203.7	203.2	202.7	202.2	201.7	201.1
	200.6	199.9	199.3	1.0000E+30	194.8	194.7	194.7	194.7	194.7	194.6
	194.6	194.6	194.6	194.6	194.6					
8	207.9	205.9	205.0	204.2	203.6	203.1	202.7	202.2	201.7	201.2
	200.6	199.9	199.0	1.0000E+30	194.8	194.8	194.7	194.7	194.7	194.7
	194.6	194.6	194.6	194.6	194.6					
9	208.5	206.1	205.2	204.6	203.9	203.4	203.0	202.6	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	194.8	194.8	194.8	194.7	194.7	194.7
	194.7	194.7	194.7	194.6	194.6					
10	209.4	1.0000E+30	205.5	205.0	204.4	203.9	203.4	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	194.8	194.8	194.8	194.8	194.7	194.7
	194.7	194.7	194.7	194.7	194.7					
11	210.5	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	194.8	194.8	194.8	194.8	194.8	194.8
	194.7	194.7	194.7	194.7	194.7					
12	211.5	209.4	208.6	207.5	207.0	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	194.9	194.9	194.8	194.8	194.8	194.8
	194.8	194.8	194.7	194.7	194.7					
13	212.5	211.0	210.0	1.0000E+30	1.0000E+30	1.0000E+30	205.5	205.1	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	194.9	194.9	194.9	194.8	194.8	194.8
	194.8	194.8	194.8	194.8	194.8					
14	213.8	212.2	211.1	210.0	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	194.9	194.9	194.9	194.9	194.8	194.8
	194.8	194.8	194.8	194.8	194.8					
15	215.3	213.4	212.0	210.4	209.3	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	195.0	194.9	194.9	194.9	194.9	194.8
	194.8	194.8	194.8	194.8	194.8					

16	216.7	214.7	213.3	1.0000E+30	209.6	208.9	208.1	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	195.0	195.0	194.9	194.9	194.9	194.9
	194.8	194.8	194.8	194.8	194.8					
17	217.9	215.8	214.1	1.0000E+30	1.0000E+30	1.0000E+30	208.6	208.3	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	195.0	195.0	195.0	194.9	194.9	194.9
	194.9	194.8	194.8	194.8	1000.					
18	219.5	217.1	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	209.2	208.6	208.3	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	195.1	195.1	195.0	195.0	194.9	194.9
	194.9	1000.	1000.	1000.	1000.					
19	221.0	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	210.1	209.6	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	195.1	195.1	195.0	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
20	222.5	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	195.1	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
21	223.5	222.1	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30	1.0000E+30
	1.0000E+30	212.7	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
22	224.3	222.6	221.7	1.0000E+30	1.0000E+30	221.0	220.7	220.7	220.7	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
23	224.7	223.3	222.6	222.5	222.2	222.3	221.4	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
24	225.0	224.1	223.7	224.1	223.7	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
25	225.2	225.1	224.8	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					

HEAD IN LAYER 2 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20
	21	22	23	24	25					
1	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	194.5	194.5	194.4	194.4
	194.4	194.5	194.5	194.5	194.5					
2	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.

ORIGINAL (Red)

	1000.	1000.	1000.	1000.	1000.	1000.	194.5	194.5	194.5	194.4
	194.5	194.5	194.5	194.5	194.5					
3	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	194.7	194.7	194.6	194.6	194.5	194.5
	194.5	194.5	194.5	194.5	194.5					
4	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	195.8	194.8	194.7	194.7	194.6	194.6	194.5
	194.5	194.5	194.6	194.6	194.6					
5	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	199.5	199.1	196.7	194.9	194.7	194.7	194.6	194.6	194.6
	194.6	194.6	194.6	194.6	194.6					
6	205.6	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	200.2	199.9	199.3	197.0	195.0	194.8	194.7	194.7	194.6	194.6
	194.6	194.6	194.6	194.6	194.6					
7	205.1	205.6	205.0	204.3	203.7	203.2	202.7	202.2	201.7	201.1
	200.5	199.9	199.2	197.0	195.0	194.8	194.7	194.7	194.7	194.6
	194.6	194.6	194.6	194.6	194.6					
8	205.0	205.8	205.0	204.2	203.6	203.1	202.7	202.2	201.7	201.2
	200.5	199.8	198.9	196.9	195.1	194.8	194.7	194.7	194.7	194.7
	194.7	194.7	194.7	194.7	194.7					
9	205.3	206.0	205.2	204.6	204.0	203.5	203.0	202.6	201.9	201.2
	200.4	199.5	198.3	196.8	195.1	194.8	194.8	194.7	194.7	194.7
	194.7	194.7	194.7	194.7	194.7					
10	205.9	206.1	205.6	205.1	204.5	203.9	203.5	202.9	202.2	201.4
	200.5	199.4	198.2	196.7	195.1	194.9	194.8	194.8	194.7	194.7
	194.7	194.7	194.7	194.7	194.7					
11	206.3	206.8	206.6	206.1	205.6	204.9	204.2	203.4	202.6	201.7
	200.7	199.5	198.2	196.8	195.2	194.9	194.8	194.8	194.8	194.8
	194.7	194.7	194.7	194.7	194.7					
12	206.8	208.2	207.9	207.4	206.7	205.8	204.9	204.0	203.1	202.1
	201.0	199.7	198.4	196.9	195.5	194.9	194.8	194.8	194.8	194.8
	194.8	194.8	194.8	194.8	194.8					
13	207.5	208.9	208.9	208.3	207.5	206.6	205.6	204.7	203.7	202.6
	201.4	200.1	198.6	197.1	195.6	194.9	194.9	194.8	194.8	194.8
	194.8	194.8	194.8	194.8	194.8					
14	207.9	209.5	209.9	209.5	208.4	207.4	206.4	205.4	204.4	203.2
	201.9	200.5	198.9	197.2	195.3	194.9	194.9	194.9	194.8	194.8
	194.8	194.8	194.8	194.8	194.8					
15	208.8	210.3	210.6	210.2	209.2	208.2	207.2	206.2	205.1	203.9
	202.6	201.1	199.4	197.5	195.7	195.0	194.9	194.9	194.9	194.8
	194.8	194.8	194.8	194.8	194.8					
16	209.8	211.1	211.2	210.6	209.7	208.9	208.0	207.0	206.0	204.8
	[illegible]	202.0	200.1	197.9	195.[illegible]	195.0	194.9	194.9	194.9	194.9

ORIGINAL (Red)

AR100466

	194.8	194.8	194.8	194.8	194.8					
17	210.6	211.9	211.8	211.1	210.4	209.6	208.7	207.9	206.9	205.8
	204.6	203.1	201.2	198.6	195.3	195.0	195.0	194.9	194.9	194.9
	194.9	194.8	194.8	194.8	1000.					
18	211.5	212.5	212.2	211.7	211.1	210.4	209.5	208.8	207.9	207.0
	205.9	204.7	202.9	200.0	195.5	195.1	195.0	195.0	194.9	194.9
	194.9	1000.	1000.	1000.	1000.					
19	212.5	213.0	212.9	212.5	211.9	211.2	210.4	209.7	209.0	208.3
	207.5	206.7	205.7	203.2	197.5	195.4	195.1	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
20	213.2	213.9	213.8	213.4	212.8	212.1	211.4	210.6	210.0	209.6
	209.2	209.1	209.9	209.5	209.1	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
21	214.2	215.6	215.1	214.5	213.8	213.1	212.4	211.4	210.9	210.8
	210.6	210.4	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
22	215.1	216.7	216.7	215.6	214.8	214.3	213.5	211.8	211.5	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
23	216.0	217.4	217.4	216.4	215.4	213.4	212.8	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
24	216.6	217.5	217.1	215.2	214.7	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					
25	217.2	216.6	216.0	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
	1000.	1000.	1000.	1000.	1000.					

VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1

CUMULATIVE VOLUMES L**3

IN:

STORAGE =	0.00000E+00
CONSTANT HEAD =	112.64
RIVER LEAKAGE =	51.759
TOTAL IN =	164.40

OUT:

RATES FOR THIS TIME STEP L**3/T

IN:

STORAGE =	0.00000E+00
CONSTANT HEAD =	0.13037E-02
RIVER LEAKAGE =	0.59906E-03
TOTAL IN =	0.19028E-02

OUT:

ORIGINAL (Red)

AR100467

AR10046?

```
        STORAGE =   0.00000E+00                              STORAGE =   0.00000E+00
  CONSTANT HEAD =    69.532                            CONSTANT HEAD =   0.80477E-03
  RIVER LEAKAGE =    96.663                            RIVER LEAKAGE =   0.11188E-02
      TOTAL OUT =    166.20                                TOTAL OUT =   0.19236E-02
       IN - OUT =   -1.7962                                 IN - OUT =  -0.20789E-04
PERCENT DISCREPANCY =            -1.09             PERCENT DISCREPANCY =              -1.09
```

TIME SUMMARY AT END OF TIME STEP 1 IN STRESS PERIOD 1

	SECONDS	MINUTES	HOURS	DAYS	YEARS
TIME STEP LENGTH	86400.0	1440.00	24.0000	1.00000	0.273785E-02
STRESS PERIOD TIME	86400.0	1440.00	24.0000	1.00000	0.273785E-02
TOTAL SIMULATION TIME	86400.0	1440.00	24.0000	1.00000	0.273785E-02

ORIGINAL
(Red)

ORIGINAL
(Red)

APPENDIX FOUR

STRATIGRAPHIC CROSS-SECTIONS

BENNETT & WILLIAMS, IN

STRATIGRAPHIC CROSS-SECTIONS

The stratigraphic cross-sections shown in Figures B through G were constructed from boring logs shown in Appendix 1, and field observations. Boring location are shown on the cross-sections, and boring or well designations are given above the sections. Symbols used to construct the cross-sections are shown in Figure A. Elevations shown on the cross-sections are in feet above mean sea level.

Horizontal scale for the cross-section is one inch equals one hundred feet; vertical scale is one inch equals ten feet. The vertical exaggeration used is ten times.

Fig. A - Symbols used in stratigraphic cross-sections A-A' through F-F'

Fill	Friable clayey sand
Clay	Loosely cemented clayey sand
Sandy clay	Weathered granite
Silt	Silty clay and sand
Clayey sand	Granite

ORIGINAL
(Red)

APPENDIX 5

AR100472

COMMENTS ON THE FIRST DRAFT FROM EPA REGION III

ORIGINAL (Red)

Upon completion of the first draft of this report, comments on the draft were invited. Comments were received from EPA region III. The comments and responses are included in this appendix.

Page 5; Paragraph 2

Add existing well specifications to Table 1
Existing well specifications are in Appendix 1, wells GMW1, GMW 2, GMW 3, GMW 4, GMW 5.

Page 16; Paragraph 1

No cross-section descriptions in Appendix 4.
This has been corrected in the text.

Page 16; Paragraph 1

Appendix 3 should read Appendix 4.
This has been corrected in the text.

Page 20; Paragraph 1

Where is the hardpan absent, cannot tell from the cross-sections.
Absence of the friable sandy clay is shown on cross-sections as areas where friable sandy clay grades into weathered granite.

Page 23; Paragraph 1

Are deep wells in the granite for water supply?
Yes.

Page 23; Paragraph 1

Why do deep wells produce from the same fracture system?
The speculation is based on the previous experiences in the area.

Page 23; Paragraph 2

Why do you suspect the two aquifers are not connected?
Several "dry holes" have been drilled into the granite in the area.

Page 25; Paragraph 1

Is there an area trend to T values?
There is insufficient data to determine trends conclusively.

Page 25; Paragraph 2

Why does the lower aquifer have to have anything to do with the standing water?

In the area of the standing water, the friable sandy clay unit is absent and therefore, there is interconnection between the upper and lower aquifer. Thus the standing water is an expression of the lower aquifer.

Page 25; Paragraph 2

Is the topographic depression the reason for the standing water?

Yes. From Plate 5, it can be seen that the potentiometric surface of the shallow perched water table is greater than the surface elevation. Therefore, the standing water is an expression of the surface elevation.

Page 27; Paragraph 1

Where is the saturated thickness of the upper aquifer equal to 0.0?

In the center of the site the shallow perched aquifer becomes seasonally unsaturated thus reducing the saturated thickness to 0.0.

Page 28; Paragraph 2

If the sediments are unsaturated, there would be no flow gradients.

The wording is changed in the text.

Page 30; Paragraph 1

Interconnection and downward movement would cause the upper aquifer to have a higher head.

This has been changed and clarified in the text.If the hydraulic conductivity is increased due to an increase in the permeability of the restricting layer, then there would be gravity drainage from the shallow aquifer to the deep aquifer if the shallow aquifer has a higher head.

Page 30; Paragraph 2

Upward flow of ground-water would not result in a decrease of head in the lower aquifer.

Discharging of water from the lower aquifer causes the pressure to decrease in that aquifer. This decrease in pressure causes the head to decrease.

Page 31; Paragraph 2

A simpler conceptual model for ground-water flow should have been introduced in the previous section.
These relationships were not clearly understood until the ground-water simulations were undertaken, therefore these conclusions are presented in this section.

Page 37; Paragraph 2

Change ground-water to saturated zone.
The wording has been changed in the text.

Page 40; Paragraph 2

Flushing sounds like an active process?
Flushing refers to repeated forced gravity drainage.

Page 40; Paragraph 4

Does this not depend on the amount of immiscible liquid there is?
The minimal saturation of the pore volume is considered to be the minimum residual saturation in the presence of an immiscible fluid. This discussion is presented to demonstrated that simply by repeated flushing, ie. heavy pumping, the immiscible liquids can not be physically removed from the aquifer.

Page 41; Paragraph 1

Define snap-off.
Snap-off: Process whereby a small droplet separates from a larger portion of liquid.

Page 41; Paragraph 1

Why do the immiscible liquids agglomerate into strings? Is it related to soil structure?
Droplets move as a response to the induced hydraulic gradient. As the droplets move, they contact other droplets and agglomerate.

Page 42; Paragraph 1

Define viscous forces.
Viscosity is an intrinsic property of a liquid, and is related to the liquid's ability to flow. If a force, such as a hydraulic gradient, is applied to a liquid, the viscosity, or shear resistance, of the liquid may be represented as a force opposing the hydraulic gradient.

ORIGIN

Page 45; Paragraph 2

Reference for K2/K1 approximately equal to 100.
K1 and K2 refer to the permeabilities of layers 1 and 2 (Figure 5). This has been clarified in the text.

Page 50; Paragraph 2

Change "thicknesses having the greatest" to "thickness of the higher".
Changing this would alter the meaning. It is the thicknesses of the soils that is discussed.

Page 50; Paragraph 4

Does Figure 7 show 43,000 ft^2?
Yes.

Page 52; Paragraph 2

What does saturation have to do with the movement of dense immiscible liquids?
In the areas on-site where the shallow perched water table, and a portion of the underlying friable clayey sand unit, become seasonally unsaturated, capillary pressures may induce the flow of liquid downward to the zone where pressure is less than atmospheric. In addition, it is possible that gravity drainage of light immiscible liquids occurs under unsaturated conditions. Because the necessary analyses were not performed to determine the nature (or density) of the liquids behaving in this manner, the text has been changed to "It may be possible for immiscible liquids to enter...".

Page 53; Paragraph 2

Does Figure 7 show 134,000 ft^2?
Yes.

Page 53; Paragraph 3

Why were the soils not analyzed for other contaminants?
Data for other soil contaminants were not available due to instrument failure at the laboratory.

Page 53; Paragraph 3

Only 58 samples on Table 6.
The text and Table 6 have been corrected to show 62 samples.

Page 53; Paragraph 3

47 mg/kg is not on Table 6.
Table 6 has been corrected and 47 mg/kg is from sample CS from a depth of 70-75".

Page 55 & Page 56; Paragraph 1

The contours do not correspond to the 46Ø mg/kg value for GS and 16Ø mg/kg value for CS.
Figure 8 shows data on samples taken from depths of 2" to 2'. High concentrations of TRP in CS and GS at greater depths are discussed in the text.

Page 56; Paragraph 1

Other causes of contamination may also be at work.
The use of the term contaminated runoff is meant to imply sources such as spills and lagoon leakage.

Page 59; Paragraph 1

Contouring on Plate 7 seems overly imaginative.
The contouring on Plate 7 best fits the data and field observations from this site. It is based on analyses, and surface run off routes.

Page 63; Table 9

Which are shallow and which are deep?
All the samples on Table 9 are from the deep aquifer.

Page 64; Paragraph 3

Need convenient reference as to which wells are shallow and which are deep.
In general, wells with "A" following the well number denote shallow wells.

Page 64; Paragraph 2

Any reason to suspect the high concentrations shown in Figure 1Ø.
The areas of high concentration in Figure 1Ø are areas where immiscible liquids are present. We suspect that the contaminant concentrations will be close to the saturation point.

Page 64; Paragraph 3

Why are CCA concentrations possibly indicative of contamination?
Since background levels of copper, chromium, and arsenic are not known, it cannot be stated at which values the concentrations become anomalous.

Page 67; Paragraph 2

Should discuss the presence of these contaminants in the deeper aquifer.

ORIGINAL

This is not possible because the data is questionable and requires further investigation.

ADDENDUM TO REPORT

BENNETT & WILLIAMS, INC.
CONSULTING GEOLOGISTS

ORIGINAL (Red)

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COLUMBUS, OHIO 43229
614/882-9122

September 9, 1986

Rentokil, Inc.
SupaTimber Division
Post Office Box 2248
Norcross, Georgia 30091

Attention: I. N. Stalker

Reference: Comments from Clean Sites, Inc. on Report on Investigation of the Hydrogeology, and Contamination, at the Virginia Wood Preserving Corporation site, Richmond, Virginia.

Dear Mr. Stalker:

Enclosed are the responses to some of the comments by Clean Sites, Inc. on the referenced investigation.

Editing of the report was done to account for certain comments by Clean Sites, Inc. Other questions were responded to and the itemized questions and responses are enclosed within.

Let us know if you need additional copies of plates or of the report itself. If you have any questions or if we can be of any further service, please feel free to call us.

Very truly yours,
BENNETT & WILLIAMS, INC.

Truman W. Bennett

Truman W. Bennett
Principal Geologist

RESPONSE TO COMMENTS FROM CLEAN SITES, INC.
ON THE FIRST DRAFT

Page 3; Paragraph 2

What about CZA?
Previous investigations at the site did not analyze for zinc, therefore stating that CZA conatamination existed on-site without further investigation would be speculation.

Page 5; Paragraph 2

Does cross-connection caused by the old wells refer to aquifers?
Yes, these wells may be causing cross-connection of the aquifer.

Page 6; Paragraph 2

Where is the run-off management plan noted?
The run-off management plan is noted in the Remedial Action section.

Page 6; Paragraph 3

Only 12 monitoring wells are listed in Table 1.
The revised report has been changed to read "Locations for 14 additional monitoring wells...". Two of these wells (#6 & 7) were not installed by Bennett & Williams, Inc., and as-built information for these monitoring wells is not known at this time. These two wells are therefore not listed in Table 1. Based on the depth of the wells, it is presumed the wells are screened above bedrock. The wells are constructed of two inch diameter PVC with five foot screened sections.

Page 6; Paragraph 3

Need to identify Bennett & Williams, Inc. wells vs. previous wells.
Monitoring wells installed by Bennett & Williams, Inc. include: GMW 2A, GMW 3A, GMW 8, GMW 9, GMW 9A, GMW 1Ø, GMW 1ØA, GMW 11, GMW 11A, GMW 12, GMW 13, and GMW 14.

Page 1Ø; Table 2

Are there indicator compounds for creosote?
Refer to Table 1Ø for a list of indicator parameters for creosote and petachlorophenol.

Page 1Ø; Table2

What about xylene.
Xylene analyses would provide useful information, and xylene is listed in Table 1Ø.

Page 13; Paragraph 1

What does "probably covered after removal of the blow-down sump" mean?
The contaminated clay was probably covered over by fill after the sump was removed.

Page 15; Figure 2

ORIGINAL (Red)

All wells should be identified on each drawing.
Well numbers were not included on each figure so that pertinent data could be clearly noted. Please refer to Plate 2 for well number designation.

Page 16; Paragraph 3

Reference for jointing in granite.
Mr. Truman Bennett has done extensive work in the region; therefore the "data source" consists of numerous past projects conducted in Henrico county.

Page 19; Paragraph 2

The hardpan unit is not well enough defined to distinguish it on the cross-sections.
The hardpan is represented on the cross-sections as "friable clayey sand" (see Table A, Appendix 4).

Page 2Ø; Paragraph 2

Why is the water standing near North Run Creek if the friable clayey sand is absent?
The absence or poor development of the friable clayey sand allows ground-water interconnection (discharge or recharge, depending on the relative ground-water elevations) between the shallow perched water table and the weathered granite aquifer.

Page 2Ø; Paragraph 2

Other reports have referred to this layer as a "fragipan" which implies a specific depositional environment, whereas hardpan is a general term which includes "fragipan". If possible the layer should be defined more specifically.
Hardpan is used here as a descriptive term described in the text and is not intended to imply any depositional environment.

Page 2Ø; Paragraph 2

Are the hardpan and friable clayey sand layer the same?
Yes.

Page 20; Paragraph 2

Is the shallow perched water table seasonal?
The saturated thickness of the aquifer responds to seasonal variations in precipitation, and in some areas it appears that the existence of the shallow perched water table is seasonal.

ORIGINAL
(Red)

Page 20; Paragraph 2

If it is "or", then the two units should be delineated on the drawing?
The use of "or" in this case refers to two terms applied to the same unit.

Page 23; Paragraph 2

Did pumping one well draw down the other, or any of the monitoring wells?
During the pumping of these wells in a previous investigation, ground-water elevations were not measured.

Page 24; Paragraph 1

What about head in the wells from each unit?
Static water levels are listed in Table 5.

Page 25; Paragraph 1

I'm not sure there are enough samples to warrant a rigorous statistical analysis.
This should not be considered a rigorous statistical analysis.

Page 26; Table 4

This table is not referred to in the text.
Table 4 is referenced in Paragraph 1 on Page 28.

Page 26; Table 4

You should identify the lithologic units associated with these intervals.
In general, those intervals above 5 feet are in the shallow perched aquifer and those below 5 feet are in the weathered granite aquifer.

Page 27; Paragraph 2

Are wells screened above the hardpan?
The wells are screened above the bottom of the hardpan.

Page 28; Paragraph 2

Where is the second condition?
The other condition is discussed in page 32. Comment is noted and corrected.

ORIGINAL (Red)

Page 3Ø; Paragraph 2

There are no boundaries for an aquifer shown on Plates 4 & 5.
The recharge boundary is along Parham Rd. and the dishcharge boundary is along North Run Creek.

Page 31; Paragraph 2

Plate 6 should be large enough to show the extent of the model boundaries.
For the purposes of this report, it is not necessary that the model boundaries be shown on Plate 6.

Page 32

Were any simulations done?
No pumping simulations were done.

Page 34; Paragraph 1

What is the nature of the organic constituents that would cause the wells to be removed?
Organic compounds which are retained on the PVC material necessitate removal. Assuming remedial methods were successful in reducing organic compund concentrations in the future, trace concentrations of organics may be detected due to the organics retained on the PVC materials.

Page 34; Paragraph 3

Why does the use of bentonite and slurry cause certain parameters to be elevated?
See reference.

Page 35; Paragraph 1

Does "levels" refer to rate or depth?
"Levels" refers to rates.

Page 37; Paragraph 1

Why is there no data for possible contamination by CZA, #2 fuel oil, or xylene?
Pertinent parameters were not analyzed.

ORIGINAL
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Page 38; Paragraph 1

Check densities of creosote materials.
Densities of creosote compounds were checked and can be found in the Handbook of Chemistry and Physics, 66th Ed.

Page 43; Paragraph 1

If it is not possible to make a direct measurement in the soil then how accurate can this estimate be? Are there any lab data or empirical evidence to substantiate the estimate?
References for this discussion are:

Yaniga, Paul M. and James G. Warburton, 1984, Discrimination Between Real and Apparent Accumulation of Immiscible Hydrocarbons on the Water Table: A Theoretical and Empirical Analysis, in Proceedings of the Fourth National Symposium on Aquifer Restoration and Ground Water Monitoring, p. 311-315.

Page 48; Figure 6

Do these symbols coincide with the units on the cross-sections?
Yes.

Page 49; Paragraph 3

It would be a good idea to show these values in a table, identify the sample number and location.
The locations are given in a previous report by Environmental Laboratories, Inc.

Page 5Ø; Paragraph 1

Where is the documentation for soil sample CS TRP?
Documentation for soil sample CS is in Table 6.

Page 5Ø; Paragraph 2

Define light.
Light refers to compounds less dense than water.

Page 52; Paragraph 2

Define dense.
Dense refers to compounds more dense than water.

Page 52; Paragraph 2

Which areas have the restrictive layer missing?
The holding pond and the covered holding lagoon (see Figure 2), and some areas with standing water.

ORIGINAL

Page 52; Paragraph 3

What is dry?
The dry residue mentioned refers to a solid material as opposed to a fluid material.

Page 53; Paragraph 2

On what data is the conclusion that the retention capacity is exceeded based?
Free-flowing dense immiscible liquid was seen entering borings CS and GS after the auger was removed.

Page 59; Paragraph 2

Does available chemical analyses mean only Bennett & Williams, Inc. samples?
The chemical analyses include both Bennett & Williams, Inc. samples and analyses reported in previous studies.

Page 64; Paragraph 2

It would be helpful to delineate the extent of contamination in the weathered granite.
There is insufficient chemical anlyses to delineate contamination in each zone.

Page 64; Paragraph 3

No As analysis for well 11 in Table 8.
It should read well 14 in the text and will be changed.

Page 64; Paragraph 3

Why are CCA concentrations possibly indicative of contamination?
Since background levels of CCA are not known in the area, the level at which CCA concentrations become anomalous can not be determined.

Page 66; Paragraph 2

Was contamination reported on both blanks? If so, the analysis of the entire round may be worthless. What type of sample bottles were used and what type of liners in the caps?
Sampling was performed by Environmental Laboratories, Inc. The comment is valid and possible problems with the data have been noted in the text.

Page 67; Paragraph 1

How was product odor determined, by sniffing of by meter?
Product odor was determined by sniffing.

 ORIGINAL (Red)

An additional well cluster is needed north of the intersection of Peyton St. and Ackley Ave. Also I do not see any justification for destroying the good wells put in as a part of this study. The berm can be built around them.
Well 13 is located north of Peyton St. and Ackley Ave. A shallow well located here may provide useful data.

Page 70; Paragraph 1

Has insitu biological treatment been evaluated?
This is discussed on page 79, method 3.

Page 76; Paragraph 1

One drawing is needed that shows the wells with labels that are included in the monitoring plan.
Plate 8 identifies those wells that will be included in the monitoring plan and the labels for those wells can be found on Plate 2. Any other figure would be redundant.

Page 76; Paragraph 3

Table 10 is not adequate for EPA certification. Should use the CLF, HSL list for at least the first round and modify after that.
Table 10 lists the chemical parameters Bennett & Williams, Inc. feels will be useful in characterizing the contaminants present. It is not an attempt to satisfy regulations or EPA certification.

Page 83; Paragraph 3

Why the inconsistancy of the units?
Hydraulic conductivity describes the potential at which water can move through a medium. It has units in gpd/ft. Transmissivity is the rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient and can be represented by T=Kb. It has units in gpd/ft^2. The units are consistent.

Page 84; Paragraph 2

No analyses?
Samples were taken, but analyses were not completed because of instrument failure at the laboratory.

Page 85; Paragraph 1

Probably should plan on the removal of all old wells and install new ones as needed.
This is recommeded under Recommendation 1.

ORIGINAL (Red)

Page 86; Paragraph 1

HSL should be the determining factor for future testing. Table 1Ø lists those chemical parameters Bennett & Williams, Inc. feels will be useful in characterizing the contaminants present. It is not an attempt to satisfy regulations or EPA certification.

Page 86; Paragraph 2

Cost is not mentioned. Cost estimates are not included in this report.

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DATE OF DOCUMENT 9 September 1986

DESCRIPTON OF IMAGERY Horizontal & Vertical Scale of a Cross-Section Area

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DESCRIPTON OF IMAGERY Plate 1 - Topographic Contour Map - Contour Interval Two Feet

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DESCRIPTON OF IMAGERY Plate 4 - Potentiometric Surface Contour Map of the Disintigrated Granite Aquifer

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DESCRIPTON OF IMAGERY Plate 5 - Potentiometric Surface Contour Map of the Shallow Perched Water Table

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DESCRIPTON OF IMAGERY Plate 6- Ground Water Model Node Matrix

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DESCRIPTON OF IMAGERY Plate 7 - Estimate of Area / Extent & Total Depth of Contaminated Soil

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DESCRIPTON OF IMAGERY Horizontal : Vertical Scale of a Crossed Section Area

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DESCRIPTON OF IMAGERY Plate 8 - Possible Elements of Remedial Action Plan

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